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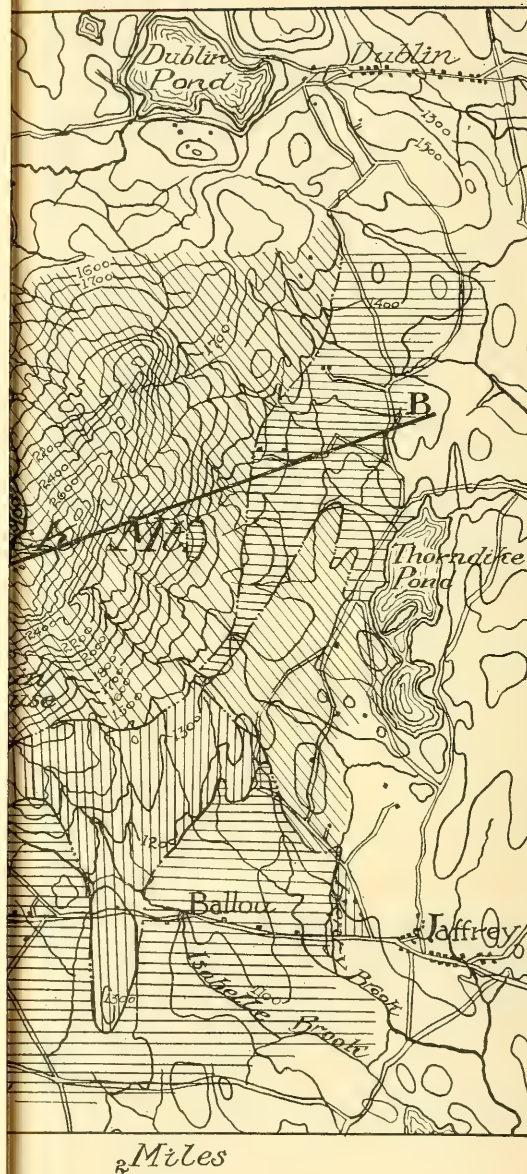
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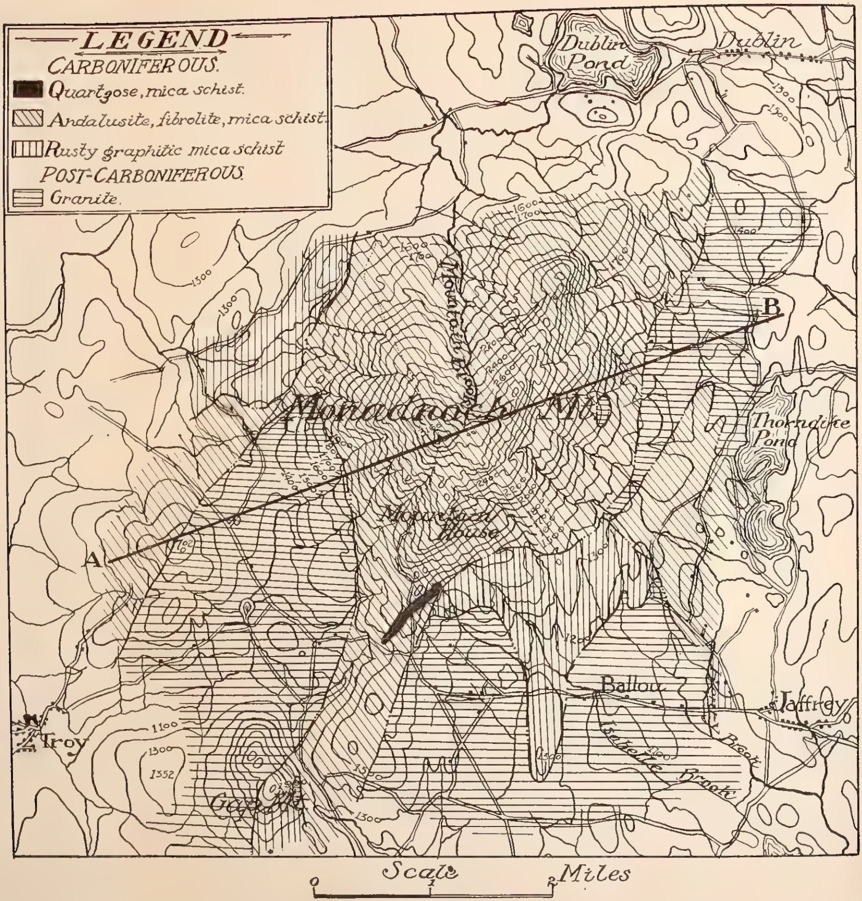
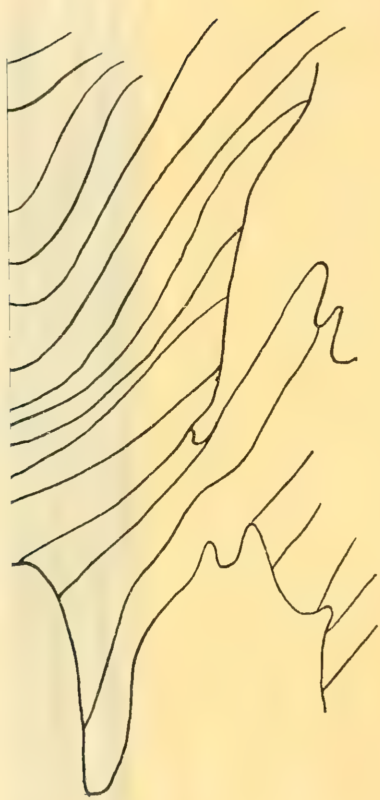

LEGEND
CARBONIFEROUS.
Quartzose, mica schist.
Andalusite, fibrolite, mica schist.
Rusty graphitic mica schist
POST-CARBONIFEROUS.
Granite.
Dublin Pond
Dublin
Monadnock Brook
Monadnock Mt.
Mountain House
Thorndike Pond
A
B
Ballou
Jaffrey
Troy
Gap Mt.
Brook
Scale Miles
0
1
2

FIG. 1.



THE

JOURNAL OF GEOLOGY

JANUARY–FEBRUARY, 1904

GEOLOGY OF MONADNOCK MOUNTAIN, NEW HAMPSHIRE.[1]

CONTENTS.

Monadnock, situated in southern New Hampshire, is of special interest to geologists because it was selected by Professor Davis as a type of the isolated, residuary peaks that may be found rising above a base-leveled land surface. This mountain rises 3,166[2] feet above mean sea-level and about 2,000 feet above the surrounding peneplain, the plateau of southern New England. At the first glance the mountain may appear, from its representation on the *Topographic Map*, as a regular, single peak; but, on

[1] Monadnock is considered in the *Geology of New Hampshire*, Vol. II, pp. 24, 503, 639. This area, with a section through the mountain, is represented on the fourth sheet of the geological map in the atlas accompanying the same.

[2] From the *Topographic Map* of the U. S. Geological Survey.

closer study of the map and of the mountain from different sides, it is seen to consist of two well-defined parts. There is a northeast-southwest ridge, about six miles in length, extending from the center of Dublin to Gap Mountain. This constitutes the eastern part of Monadnock. This ridge rises by a succession of steps from an elevation of 1,500 feet at its northern extremity to 2,800 or 2,900 at its culmination east of the summit of the mountain, and then descends by a like succession of steps to its southern extremity.

The eastern slope of this ridge above the foothills is quite steep, even precipitous. The western part of the mountain, which includes the summit, rising 300–400 feet above the eastern ridge, consists of a single peak set, as it were, in the central part of the western slope of the ridge. The northwest slope of this peak is gentle; the west and southwest slopes are much steeper; while the northeast slope meets the northern half of the western slope of the ridge forming the valley of Mountain Brook. These divisions and their slopes are closely related to the underlying rock structure, and indicate that erosion is controlled or guided by this structure.

The rock of this mountain is a banded mica schist, the banding being generally parallel to the present structure. The schist presents three marked variations. In the top of the mountain and in the upper part of the eastern ridge it is a gray, massive, garnetiferous, biotite, sericite schist, in which the biotite is specially noticeable because of its arrangement in bright, isolated scales, one-sixteenth of an inch in diameter, set in a fine, light gray groundmass.[1] In addition, andalusite crystals, or what were once andalusite crystals, occur in this schist, sometimes very abundantly, lying parallel to the present structure of the rock. The accompanying picture (Fig. 2) shows how abundantly these may occur in the schist. They are frequently five or six inches long by half an inch, or more, through. Owing to the unequal weathering, these prisms frequently appear in relief on the surface of the ledges. In the southern half of the

[1] In the *Geology of New Hampshire* this schist is called the Kearsarge andalusite schist.

ridge, and also in the western peak of the mountain, these prisms are now largely, if not entirely, made up of fine, glassy, colorless or white fibers of fibrolite. In the northern part of the eastern ridge, and in other parts of the mountain in limited areas, the andalusite crystals have changed to masses of white, pearly sericite scales. In the weathering these sericite masses

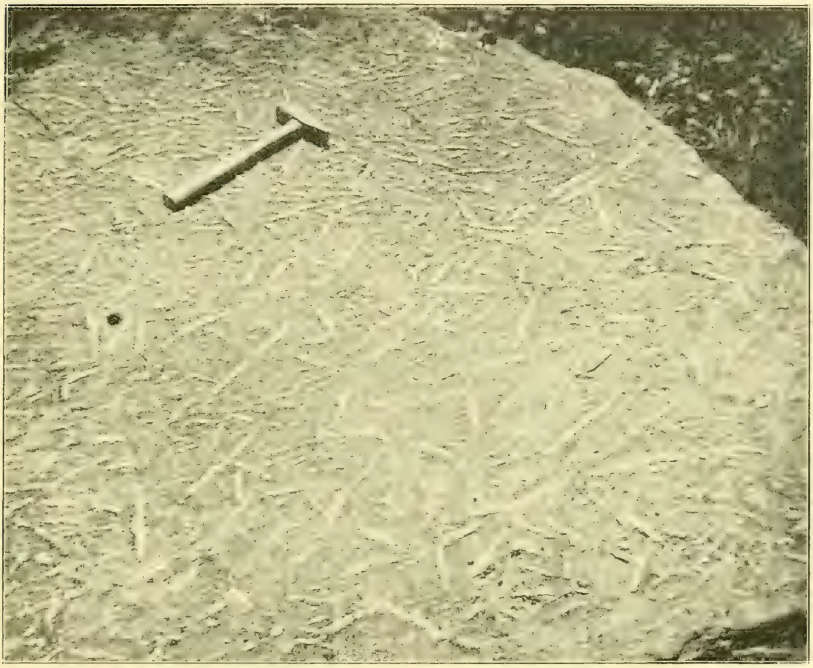


FIG. 2.—Surface of Andalusite mica schist.

are removed more rapidly than is the inclosing rock, producing long narrow cavities on weathered surfaces. Where the end of the sericite mass is exposed, the weathering is more rapid in the center, producing a cavity bordered by a sericite shell.

In the southern part of the mountain the schist becomes, by alternating areas, a fibrolite schist, the fibrolite being original; but even within this fibrolitic area appear small areas where the rock originally contained andalusites. It is impossible to draw a line correctly separating this schist into two parts, so

intimately associated are the original fibrolite and pseudomorphs after andalusite. As the schist becomes fibrolitic, it is distinctly and quite thinly laminated. It also contains garnets and tourmaline and, rarely, graphite in fine scales.

In the middle of the northeast slope this schist is destitute of fibrolite and pseudomorphs of andalusite; it is characterized by a dark green mica of soapy feel, and a very fine, white sericite. The latter is in fibers as fine as the fibers of fibrolite, and occurs in the schist just as fibrolite occurs in other parts of this schist. The sericite is evidently fibrolite changed into sericite, as is proved by the finding of a mass of fibrolite partly so changed. In the general sericitization to which this schist has been subjected the fibrolite, in places, has been changed as well as the other minerals. This sericitization indicates the permeation of this schist by potash solutions. These variants are considered as one schist, and are so colored on the geological map.

The second phase of the mica schist, found in the mountain and the surrounding area, may be seen between the 1,600 and 1,700-foot levels on either side of the road on the southern slope. It is a gray, thinly laminated, finely granular, quartzose mica schist, containing, in addition to the granular, glassy quartz, a little fine, brown mica and fine, light green hornblende. This schist is cut by lamination planes and joints into thin, rectangular slabs. In position it is conformable with the fibrolite-andalusite schist above. The boundary between the two is a zone of alternation. This indicates either an alternation of sediments or an interfolding along the border. I judge that the former is the case here, because in other parts of this area the quartzose schist blends into, and alternates with, the third phase of the mica schist. In only this small area on the southern slope is there enough of this quartzose schist by itself to be represented as a distinct area on the map.

The third phase of the mica schist occurs below the second, on the southern slope, and is the first rock met in going up the mountain road. This is a very rusty, thinly laminated, frequently fissile, muscovite, biotite schist which often becomes so quartzose as to be a micaceous quartzite. The extreme rustiness

is due to iron pyrites. Little scales of graphite are characteristic of this phase of schist, and are sometimes abundant enough to give a gray color to the unrusted rock. Fibrolite was not observed with the graphite, though in the more micaceous, or first phase of the schist, fibrolite and graphite may sometimes be seen together. This rusty phase occurs over quite an area in the southeastern part of the region represented in our map, and also in the northwestern part, and on the southeastern slope of Gap Mountain. In all of these areas there is no well-defined border between the first or fibrolitic phase and the third or rusty, graphitic phase; there is a blending of one into the other, and they are equivalents. The second phase also is only a variant of the third.

Included in the area of the accompanying geological map, though not a part of the mountain, are granite masses which are closely connected with the rock structure of the mountain, and with other phenomena revealed in this study. Where this granite adjoins rusty schist, it has a dark gray color, is more or less rusty on weathered surfaces, and is of medium fine, granular texture.

The quartz and the feldspar form an intimate granular mixture, in which the biotite is quite uniformly distributed in fine scales. Muscovite occurs in varying quantity, but is not characteristic of the granite, as biotite is. Fine magnetite and little, brown, wedge-shaped crystals of titanite occur in this granite along with some small particles of secondary epidote. Along the immediate border the granite sometimes contains black tourmaline. Tourmaline is, however, more frequently seen in the schist.

Away from the schist the granite is lighter in color, more muscovitic and less biotitic, contains less of the other minerals—is, in fact, more nearly a simple, medium fine, crystalline mixture of feldspar, quartz and mica. In mapping the granite this variation is a good index of the nearness or remoteness of the schist border.

In places the granite, in the southern part of this area, is porphyritic, the feldspar phenocrysts sometimes measuring an inch by one quarter, and showing the Carlsbad twins. The feldspar of the groundmass is partly triclinic. The granite of the north-

eastern part of the area of our map is prevailingly porphyritic, and closely resembles the granite already described, except that the phenocrysts are frequently larger and sometimes show a granulated border. The granite of these areas is frequently foliated near the schist border, and parallelly to the lamination of the schist.

On looking at the map, it is seen that the granite in the southern part of this area occurs in lobes, two of which are connected, while that in the northeastern part is in the form of a long tongue extending far into the schist, though not visibly reaching the southern granite area. These are probably parts of an extensive batholite which, possibly, extends even under the mountain. This granite incloses fragments, both large and small, of the neighboring schists. Among these may be recognized some of the light gray, quartzose mica schist thoroughly brecciated, and some of the fibrolite and andalusite schists. In the last the andalusite crystals have been generally, if not always, changed as has been described before. Inclosed in the granite may be seen prismatic masses of sericite entirely separate from, though in the vicinity of, the schist, which probably represent andalusite crystals which were dissolved in the magma, and afterwards crystallized out and sericitized.

It is difficult to decide, in some parts of this area, where to draw the boundary between granite and schist, because there is frequently a zone of alternating bands extending in the direction of the strike. Such an area is represented in the extreme western part of the geological map, and also in cross-section. The meaning of such an area is that the surface of contact between schist and granite batholite was a ragged surface—the granite having penetrated the schist at intervals, and pushed apart the vertical laminæ. The erosion has brought the land surface down so as to make a section through this alternation. If the land surface had been lowered somewhat less, the rock at the surface would have been schist; whereas if the land surface had been lowered somewhat more, the rock would have been then all granite. As it is, the extension of the batholite is but a short distance below the surface.

In this granite are many pegmatite veins, varying from an inch to several feet in thickness, and frequently the pegmatite appears in the schists. Though there is a variation in the direction of these veins, the prevailing one is northerly in the southern granite lobes. This pegmatite material shows all grades of variation from the well-defined, coarse pegmatite to pure vein quartz; and all the variations evidently had a common origin.[1]

From what has been written, it is evident that schist and granite were modified by mutual contact. The extensive sericitization of one and the darkening of the other by the increase of biotite are the most noticeable effects. From these contact phenomena and from the schist inclusions in the granite it is evident that the granite is intrusive and younger than the schist.

In rocks so thoroughly recrystallized as are the schists of our study no fossils can be expected, but the graphite found in both the rusty graphitic schist and also, though rarely, in the fibrolitic schist may point back to organic remains.[2] To one acquainted with the rocks in the plateau of central Massachusetts, from Worcester to the Connecticut Valley, it is evident that these schists in and around Monadnock are but a continuation of the Massachusetts rocks, though there may be a few square miles of area between the two not yet mapped; and the conclusions that have been reached from the study of the latter are applicable to the former. After many years of study, Professor Emerson and the writer have concluded that the schists of this plateau in Massachusetts are more highly metamorphosed phases of the Carboniferous phyllite and quartzite found at Worcester.[3] If this conclusion is correct, then these schists of Monadnock are Carboniferous, and the intruded granite is post-Carboniferous.

Another fact demanding careful study is the attitude of the schist in this mountain. That the structure is not as simple as it might be is indicated by the statement on p. 639, Vol. II, of

[1] J. E. SPURR, "Genesis of Auriferous Quartz Veins," *Eighteenth Annual Report of the U. S. Geological Survey*, Part III, pp. 311, 313.

[2] In the *Geology of New Hampshire*, Vol. II, p. 503, a graphite mine in this schist is mentioned.

[3] *Geology of Worcester, Massachusetts*, pp. 28, 50, 137, 139, 148, 152.

the *Geology of New Hampshire*: "In structure it (Monadnock), seems to be a double synclinal. Again, on p. 24, it is stated: "Mt. Monadnock seems to be an isolated, contorted synclinal of andalusite mica schist." The strike of the schist in the area east of the mountain, in the eastern slope, and in the northeast half of the ridge of the mountain, is between north and northeast, with a dip to the west and northwest. In the southern half of the ridge, as far north as an east-west line passing through the more southerly of the two houses on the mountain road, the strike is from north to almost east, with the dip to the northwest. In the top and in the northwestern part of the mountain the strike is

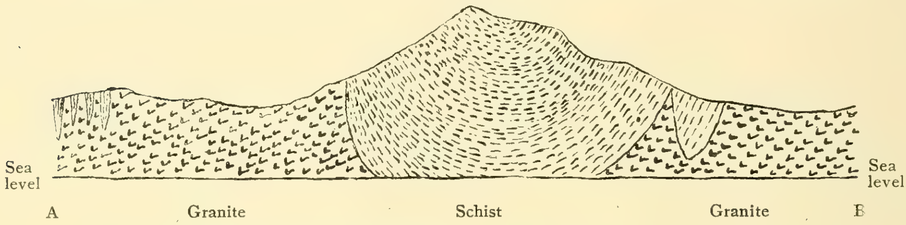


FIG. 3.—Section through Monadnock. Horizontal scale $\frac{1}{62500}$; vertical scale $\frac{2}{62500}$; made from Topographic Map of U. S. Geol. Surv.

to the northwest, with a dip to the northeast. In the extreme western part of the area here included, the strike is east and west north of the granite lobe with the dip varying from vertical to 40° south; and the strike is northeast on the northwest side of the same lobe, with the dip vertical. In the central part of the mountain mass, between the northeasterly and northwesterly strikes, the strike swings from one to the other through an east-west direction, with a dip of about 45° to the north.

The meaning of this variation in the dip and strike is that the schist in the northern two-thirds of this mountain mass has been folded into a synclinal having a pitch of 45° to the north; and the western limb of this synclinal is continued in an overturned anticline, with pitch to the south, around the western granite lobe. The axis of the syncline is marked, approximately by the course of Mountain Brook down the northern slope. The highest point of the mountain is not at the apex of the syncline, but is in the

western limb. South of the summit this syncline may be traced along the crest of the ridge, becoming narrower, as far as the east-west line of the more southerly house on the mountain; south of this line, along the continuation of the axis of the syncline, there is a marked deviation of the strike to the east,

FIG. 4.—Showing the jointing in schist. West side of Monadnock, 2800-foot level, looking southeast. The joint plane slants toward the right. The dip is toward the left.

which becomes less and less as the syncline fades out to the south.

On the transparent sheet accompanying the geological map the folds in the schist are represented. The lines of strike were first plotted, and then these curves were drawn through them. In this way the anticline in the schist, as it folds around the granite lobe in the west, and the syncline in the mountain itself

are clearly brought out. A glance at this sheet is sufficient to convince anyone that the folding of the schist accompanied, and was due to, the intrusion of the granite; and the force of intrusion was exerted in a northerly direction.

Closely connected with the folding is the jointing in this schist, which is very noticeable in every part of the mountain, but especially above the line of vegetation. Here the rock has been broken into large blocks, perhaps 20–30 feet long by 10–15 feet thick and wide, and these are so placed in the mountain as to make a series of steps, as is shown in the accompanying illustration (Fig. 4). This picture was taken at about the 2,900-foot level, and on the western side of the mountain. Observations of the direction and slant or dip of these joint surfaces were made up on the mountain where there was little or no vegetation, and on different sides; and they are arranged in the table below. While there are not so many observations as there well might be, they make clear certain facts or relations.

Side of Mountain and Elevation	Strike of Banding — True Strike	Dip of Banding — True Dip	Joint 1 — Strike or Direction	Joint 1 — Dip or Slope of Surface	Joint 2 — Strike or Direction	Joint 2 — Dip or Slope of Surface	Angle between Strikes of Joints 1 and 2	Angle between Dip and Dip of Joint 1
South ridge, southeast of top, 2,500 level	*70° W	45° N	80° E	......	......	......	..	..
Southwest of top, 2,850 level	*35° W	35° N E	45° W	65° S W	5° E	25° W	50	80
West of top, 2,800 level	*N & S	45° E	35° W	60° S W	E & W	Vertical	55	..
Northwest of top, 2,800 level	N & S	45° E	50° E	70° N W	80° W	75° S	50	..
North 30° west of top, 2,800 level	*20° E	40° E	32° W	60° S W	60° E	33° S E	92	..
North of top, 2,800 level	35° E	60° E	40° E	25° N W	65° W	Vertical	75	95
West side of mountain, 1,900 level	*65° W	25° N E	55° W	70° S W	60° E	40° S E	65	85
Northwest side in Marlboro trail, 2,200 level	*50° W	55° N E	55° W	35° S W	......	......	..	90
Northeast side, 2,200 level	*35° E	45° W	45° E	65° S E	......	......	..	70
Northeast side, 2,400 level	*35° E	33° W	35° E	60° S E	75° E	90°	40	87
Northeast side, 2,500 level	*35° E	38° W	35° E	90°	70° W	75° S W	75	52
Northeast side, 2,700 level	18° E	35° W	45° W	90°	85° E	80° S	50	

1. In nine marked by a *, out of the twelve, the direction of joint 1 is approximately the same as the strike of the banding; or where the banding departs by local folding from parallelism with the side of the syncline, joint 1 is parallel to the side of the syncline.

2. The angle between the strike, or direction of joint 1, and

the strike, or direction of joint 2, varies from 40° to 90°, but in five cases out of the nine is between 50° and 65°.

3. The angle between the true dip and the dip of the surface of joint 1 in five, out of seven, cases approximates to a right angle.

The meaning of observations 1 and 3 is that this schist has been broken perpendicularly to the laminæ into strips from one end of the syncline around to the other; and observation 2 shows that these strips have been broken crosswise, less regularly, into shorter pieces or blocks, the latter indicating a bending or twisting in these strips. There is, I think, no doubt but that these joints were produced by the bending of the schist into the great synclinal fold of the mountain, and this, as has been pointed out, accompanied the intrusion of the granite. The formation of the joints in this schist clearly indicates that this rock was in the zone of fracture when this intrusion and folding took place. The same is indicated by the brecciation appearing in some of the schist fragments included in the granite.

But there is another and earlier folding evident in this schist. The accompanying illustration shows a compressed, overturned anticline occurring near the top, on the west side, which is conspicuous for a distance of several hundred feet down the mountain to one ascending on that side. The part of the fold appearing in the picture is 37 feet long by 6 wide, and the apex of the fold as seen in this section points between northwest and north. This means that the fold is overturned and lies flat in the western side of the large syncline, with the apex of this small anticline pointing away from the apex of the large syncline. The formation of this small anticline, though the bending was so severe, was not accompanied by fracture, as may be seen in the illustration (Fig. 5). Other folds, though less conspicuous, may be seen of which the same is true, and the jointing of the schist cuts through these, indicating utter independence of the one of the other. Therefore, when these smaller folds were made the rock was in the zone of rock flowage. There are indicated, therefore, two periods of metamorphism — one at a greater depth when the clastic was recrystallized and in places severely folded without fracture; and the other at less depth

when there was extensive sericitization, development of tourmalines, and folding with fracture accompanying the intrusion of granite.

Another point of interest in the study of Monadnock is to determine, if possible, why this rockmass has survived the profound erosion to which this region has been subjected. Dr.

FIG. 5.—Fold in schist of Monadnock, near the top, on west side. Also shows banding in the schist.

Gulliver,[1] speaking of this mountain, attributes its survival to the greater resistance of the rock. In making such a comparison, it is well to bear in mind that there is an element of uncertainty in that the rocks that have been removed from above an area are not always the same, at least in this region, as those that now appear at the surface, on account of the extensive intrusions of eruptives. Dr. Haye's[2] points out, in his study of the Chattanooga district,

[1] *Bulletin of the Geological Society of America*, Vol. X, p. 19.

[2] *Nineteenth Annual Report of the U. S. Geological Survey*, Part II, p. 39.

that these residuals are the result of two factors, erodibility and location. In the case of Monadnock the second factor was probably quite as important as the first.

It must be noticed that this residuary peak does not stand alone. The one farthest south in Massachusetts, and closely related to this one, is Asnebumskit, in the town of Paxton, rising about 400 feet above the peneplain or plateau of southern New England. It is situated about a mile east of the divide between the Connecticut and the Atlantic watersheds, and at the beginning of that of the Blackstone. In preglacial times it was, very likely, on the divide between the two main watersheds. This monadnock is made up of a rusty, fribrolite schist, not to be distinguished from that in hundreds of square miles of the surrounding plateau. Next to the north is Wachusett, with two minor points associated with it, rising nearly 1,000 feet above the plateau, and situated in the town of Princeton. This is on the divide between the Ware and Nashua Rivers. It is composed of granite and the same rusty, fibrolitic mica schist, the former making up by far the larger part. There is nothing about these rocks to indicate that they are any more resisting than are similar granites and schists in the surrounding plateau. Watatic, situated in the town of Ashburnham and rising about 700 feet above the plateau, is another monadnock situated on this divide. With the rocks of this mountain I am unacquainted. Then, crossing the state line into New Hampshire, we find Monadnock also on the same divide. There are more, though smaller, residuary peaks east and west of this; and to the north still others, even rivaling Monadnock. This is just what might be expected, even in a region made up of rocks of uniform resistance—incomplete peneplanation up toward the sources of the main streams, while it is almost complete farther to the south towards the mouths of these streams. My conclusion from the study of the rocks is that these monadnocks, situated along on the divide from central Massachusetts into southern New Hampshire, owe their survival to their position rather than to the rocks of which they are composed; for in a region made up of rocks of uniform resistance and subjected to peneplanation there would be some points up

near the sources of the main streams which would be the last to be brought low.[1]

SUMMARY.

1. This mountain is made out of a syncline in andalusite-fibrolite schist, probably of Carboniferous age. The syncline was produced by the intrusion of granite, which modified the schist already metamorphosed.

2. The schist contains andalusites changed to fibrolite and sericite, also fibrolite changed to sericite.

3. The jointing of the schist was produced by the folding; therefore the intrusion of the granite, which produced the folding, took place when the schist was in the zone of fracture.

4. There is an older folding evident, which must have been produced when the schist was in the zone of flowage.

5. This mountain and the other monadnocks to the south on the Atlantic-Connecticut River divide, probably owe their survival to their position, rather than to the greater resistance of the rocks composing them.

JOSEPH H. PERRY.

WORCESTER, MASS.

[1] Mount Grace, in Warwick, Mass., rising about 500 feet above this plateau, and situated about six miles from the Connecticut, far to the west of the divide, owes its survival, probably, to the greater resistance of its rocks. It is made up largely, or entirely, of amphibolites, while the surrounding plateau is made up of mica schists and granite.

ON A CALIFORNIA ROOFING SLATE OF IGNEOUS ORIGIN.[1]

DURING the field season of 1903 the writer was enabled to spend several days in the study of the important roofing-slate deposits occurring north of Placerville, El Dorado county, California. A summary of the principal economic results of this investigation will soon appear in a bulletin[2] of the United States Geological Survey; while a more detailed description, with maps, will probably be issued later as one chapter in a Survey bulletin on the slate deposits of the United States.

One result of the study, however, would seem to be of sufficient novelty and general geologic interest to be worthy of discussion in this JOURNAL, in considerable detail. This is the determination that a part of the roofing slates of the El Dorado county district have been derived, by dynamic metamorphism, from basic igneous rocks—gabbros or related types.

THE CALIFORNIA SLATE DEPOSITS IN GENERAL.

Location and general relations.—Though roofing slate has at different times been quarried, on a small scale, in other parts of the state, the only important slate-producing area in California is located in El Dorado county. The quarries which have been opened in this district are located along a line running about N. 15° W. from Placerville, at distances of from one to six miles from that town. The location and general relations, both geographical and geological, of the slate deposits and quarries, can best be understood by reference to the maps included in the "Placerville Folio" of the United States Geological Survey. The workable roofing-slate deposits of this district occur in a belt of the Mariposa slates, of late Jurassic or early Cretaceous age. The quarries which have been opened are all situated near the western boundary of this belt of Mariposa slates, where it is

[1] Published by permission of the director of the U. S. Geological Survey.

[2] *Contributions to Economic Geology*, 1903.

bordered by a large area of diabase. This diabase has been described[1] by Lindgren and Turner as being "of the age of the Mariposa slates, or older." A number of linear areas of amphibolite occur in the Mariposa slates. These amphibolites are described as being derived from diabase or gabbro. They are in part altered to serpentine.

Previous work on the slate deposits.—The "Placerville Folio," No. 3, U. S. Geological Survey, published in 1894, contains the results of detailed geologic work by Lindgren and Turner in the area in which the roofing-slate deposits occur. At that date the roofing-slate industry had not assumed its present importance, though all the quarries now in existence had then been opened. The existence of roofing-slate deposits is noted in the text of the folio, and the locations of the quarries are indicated on the map showing the economic geology of the area. No reference is made to the "green slates," or to the dikes cutting the Eureka quarry.

Excellent, though brief, descriptions of the different quarries and of the condition of the slate industry at various dates are to be found in the *Reports of the State Mineralogist of California*; particularly in the eighth and twelfth reports.

At present the most important quarry is that of the Eureka Slate Co., and this is now being worked on a large scale. This quarry is located at Slatington, about one-half mile southwest from the point where Kelsey is shown on the Placerville atlas sheet.

Structural relations in Eureka quarry.—The cleavage planes of the slates in the Eureka quarry strike N. 25° W. The dip of the cleavage is practically vertical, with slight local variations to 80° E. or 80° W. The upper weathered beds in the quarry are overturned, by local pressure, so as to give 40° to 60° dips to the east or west, according to local conditions. This overturning is evidently due merely to the weight of the overlying soil and decomposed slate, and the effects are shown only for a depth of from 3 to 15 feet. It is of interest, however, as a warning against accepting dip readings taken from surface beds of the slate.

[1] "Placerville Folio," U. S. Geological Survey; legend of "Areal Geology" sheet.

The slate body shows rather frequent, but narrow, "ribbons." These ribbons are bands (from $\frac{1}{16}$ to $\frac{1}{2}$ inch thick usually, but occasionally as thick as two inches) of material differing in composition from the mass of the slate. They are in general more siliceous than the normal slate, and do not furnish merchantable material. Their geologic interest arises from the fact that they represent differences of original sedimentation. The plane of the ribbons in a slate quarry is therefore the plane of original bedding. In the Eureka quarry, and, indeed, throughout the roofing-slate belt, the plane of original bedding seems to be usually within ten degrees of the plane of slaty cleavage.

The slate mass is cut by a series of joints, *parallel* to the "grain" of the slates, striking N. 55° E., and dipping from 70° to 80° to the northwest. Joints *across* the "grain" of the slate, which would be practically horizontal, do not occur in this quarry; but many of the thin quartz seams occupy this position.

Quartz and calcite occur in thin layers, filling joint spaces and occasionally cleavage spaces. Pyrite also occurs in very much flattened nodules, which were apparently parallel to the original bedding.

Character of the normal slate.—The mass of the Eureka quarry product is a dense, deep black slate, splitting very finely and regularly, with a smooth glistening surface much like that of the Bangor and Lehigh slates of Pennsylvania. The frequency of the ribbons, and of the pyrite nodules, prevents the slate from being serviceable as mill stock; but as a roofing material it is very satisfactory.

A specimen of the black slate, free from ribbon, was selected for analysis in the laboratory of the U. S. Geological Survey. The results of this analysis, by Mr. W. T. Schaller, follow:

ANALYSIS OF BLACK SLATE, EUREKA QUARRY, SLATINGTON, CALIF.

Silica (SiO_2)	63.52
Alumina (Al_2O_3) and titanic oxide (TiO_2)	16.34
Iron oxides (FeO, Fe_2O_3)	6.79
Lime (CaO)	0.98
Magnesia (MgO)	2.50
Carbon dioxide (CO_2) / Water	4.86

THE "GREEN SLATES."

Appearance and structural relations.—Perhaps the most striking feature of the quarry of the Eureka Slate Co., as seen from the old ground surface eighty feet above the present floor of the quarry, is a light green band, four feet or so in width, that extends vertically from top to bottom of the quarry, and is particularly noticeable on the higher east wall. This band furnishes the "green slate" of the quarry men. The contrast in color between this green band and the intense black of the fresh surface of the rest of the slate is very striking.

Viewed from the old ground level, one cannot determine whether the green band is parallel to the slaty cleavage or to original bedding; which planes, as noted earlier in this paper, commonly differ only by ten degrees or so. At first sight, therefore, the green band might reasonably be considered to be a mere color variation, due either to original differences in composition of the beds from which the green and black slates were derived, or to a later change in the color of certain beds; and this view has apparently been accepted by former observers.

Closer study, however, removes this easy explanation from the list of possibilities. Even a casual examination of a green slate quarried from this band, and comparison with a slate of the normal black type, are sufficient to prove that the two slates are different in more than color; while a closer examination of the character and structural relations of the green band, when seen from the quarry floor below, suffices not only to emphasize the distinction between the green slate and the black, but to suggest a somewhat novel origin for the former.

Relations of contact plane to cleavage and bedding.—On going down into the quarry and closely examining the relations of the two slates, the contact between the green and black slates is seen to be, not parallel to the "ribbon" of the black slate, which indicates the plane of original bedding, but cutting the ribbon at a small angle—not over ten degrees. It is not, however, certain that the contact plane is exactly parallel to the plane of slaty cleavage, which also cuts the bedding plane at a small angle. This detail—the relation of the contact line to the cleav-

age planes—has, of course, no bearing on the question of the derivation of the green slates. It may prove, however, to be of some importance in determining the probable cause of the origin of slaty cleavage in this particular portion of the Mariposa slate belt.

Disregarding this omission of data as to the relation of contact to cleavage plane, the fact remains that the band of green slate is not everywhere conformable to the original bedding of the Mariposa slate series. It is, therefore, highly improbable that it was an originally interbedded member of that sedimentary series; on structural grounds it is probable that it represents a mass of igneous rock, injected as a dike into the Mariposa series and, subsequently to its intrusion, so highly sheared as to have a very perfect slaty cleavage. This probability is increased when the chemical composition of the rock is considered.

Further confirmation of this hypothesis is afforded by an examination of the cross-section of the dike, which proves that it is not homogeneous in texture throughout, but that it varies in bands closely parallel to the contact plane. Along its contact with the normal black slate, the green slate is very fine-grained for an inch or so. Bordering this is a zone several inches in width, of coarser texture, and drab-green color, which is followed in turn by the typical "green slate." These differences in color and texture are sufficiently noticeable to be readily distinguishable by the quarry men and slate splitters. The textural differences are such, in fact, that the layer immediately next to the contact is discarded as a "ribbon," since it works unsatisfactorily. It must be recollected, however, that these layers are parallel to the contact, not to the "ribbon" or original bedding of the black slate.

Igneous rocks of the vicinity.—About five hundred feet west of the present quarry the western edge of the Mariposa slate is reached, a body of igneous rock limiting it in that direction. This rock is described in the "Placerville Folio" as diabase. A linear outcrop of amphibolite, trending about parallel with the cleavage of the slates, is shown on the "Areal Geology" sheet of this folio, near Kelsey, and some distance east of the Eureka

quarry. Other amphibolite dikes occur to the north and south of Kelsey.

Several other dikes, not hitherto mapped, and important in their bearing on the problem of the origin of the green slates, were noted during the recent work. These dikes outcrop between the quarry and the diabase body west of it, as narrow linear areas, trending N. 25° W., or thereabout. They are best shown, however, in a tunnel which is now being driven for drainage and working purposes. This tunnel starts in the Kelsey ravine, which marks the boundary between the diabase and the Mariposa slates; and runs eastward to the quarry, coming in at about twenty feet below its present floor level.

This tunnel intersects three dikes, in addition to cutting the green band of the quarry. Of these dikes, two show material which is fairly massive, while the third, the one nearest to the green band, seems to have a decidedly slaty structure, though not sufficiently so as to be utilized as a source of roofing slate. From these observations it would seem that the intensity of the shearing, which resulted in the present slaty cleavage, increased as did the distance from the contact of the Mariposa slate and the diorite.

Microscopic investigation.—The results of microscopic investigation were of no particular service in this connection, owing to the fact that sufficient fresh material had not been secured from the various dikes.

A specimen from the dike farthest from the quarry—and nearest to the great body of diabase—was examined by Dr. Whitman Cross, who reported that it was a gabbro.

Its main constituents are augite and plagioclase, with a rude parallel arrangement of the minerals, suggesting that the specimen was derived from the neighborhood of an original dike contact. There is a small amount of brown amphibole, probably paramorphic after augite. While several joints are visible cutting the specimen, no actual shearing zones or planes were detected in the two sections prepared from this specimen.

Several specimens from the body of the "green slate" band, and also from the contact between the "green slate" band and the normal black clay-slates, were submitted to Dr. Cross for examination. The results of this study were unfortunately uncon-

clusive. Dr. Cross states that the specimens are composed largely of feldspar, calcite, chlorite, and some other minerals. All are evidently greatly sheared. They present, however, no direct evidence of derivation from the kind of rock represented by the specimen from the dike near the tunnel entrance. They contain no augite or plagioclase, as such, and show no transition in texture. While it is quite possible that these rocks may have been derived from an igneous rock like the gabbro, such derivation is not shown by microscopic examination of the specimens submitted.

Chemical investigation.—A typical specimen of the green slate, from near the middle of the band, was selected for partial analysis in the laboratory of the U. S. Geological Survey, and the results of this analysis are presented below, as No. 1. The second analysis given below was quoted to the writer by Mr. C. H. Dunton, manager of the Eureka Slate Co., but the name of the analyst was unknown to him. The two analyses agree sufficiently closely, and are probably fairly representative of the chemical composition of the green slates.

ANALYSES OF THE "GREEN SLATES" FROM SLATINGTON, CALIF.

	1	2
Silica (SiO_2)	45.15	47.30
Alumina (Al_2O_3) and titanic oxide (TiO_2)	16.33	15.53
Iron oxides (FeO, Fe_2O_3)	8.42	8.00
Lime (CaO)	6.42	7.83
Magnesia (MgO)	8.72	7.86
Akalies (Na_2O, K_2O)	n. d.	3.17
Carbon dioxide (CO_2) } Water }	11.28	9.92

1. By W. T. Schaller, U. S. Geological Survey laboratory.
2. Analyst unknown. Analysis quoted by Eureka Slate Co.

It will be seen that these analyses differ widely from those of any normal clay slate, and even if no structural evidence were at hand, the chemical composition of the green slate would be sufficient to suggest that their origin was probably from igneous, not sedimentary, rocks.

For the purpose of indicating the class of rocks from which

these green slates were probably derived, a number of analyses have been selected from Turner's papers[1] on the rocks of the Sierra Nevada, and these are presented below. The specimens analyzed were all from California localities, but none, unfortunately, from very near the El Dorado county slate deposits. None of the analyses are complete, but sufficient determinations are given in each case to permit their use for the present purpose—their comparison with the analyses, given above, of the green slate from Eureka Slate Co. quarry. The coincidence in general composition seems to be sufficiently marked to suggest, with a high degree of probability, that the green slates have been derived from some rock of type similar to those whose analyses are given in the following table:

ANALYSES OF IGNEOUS ROCKS OF THE MOTHER LODE DISTRICT, CALIFORNIA.

	1	2	3	4	5
Silica (SiO_2)	53.14	51.32	49.24	48.86	45.92
Alumina (Al_2O_3) and titanic oxide (TiO_2)	n. d.	15.28	14.79	n. d.	n. d.
Iron oxides (FeO, Fe_2O_3)	n. d.	9.06	9.52	n. d.	n. d.
Lime (CaO)	9.56	11.58	10.74	7.65	9.96
Magnesia (MgO)	4.97	7.25	6.89	9.88	13.85
Alkalies (K_2O, Na_2O)	3.29	3.14	3.64	4.82	0.81
Carbon dioxide (CO_2) / Water	n. d.	n. d.	4.07	n. d.	n. d.

1. Gabbro: east side of Eureka Peak, California; analyzed by Hillebrand and Steiger. (*Seventeenth Annual Report*, U. S. Geological Survey, Part II, p. 642.)

2. Diabase: north of Hornitos, Calif.; analyzed by Hillebrand. (*Ibid.*, p. 694.)

3. Augite porphyrite: west of Jackson, Calif.; analyzed by Hillebrand and Steiger. (*Fourteenth Annual Report*, Part II, p. 473.)

4. Augite porphyrite: Plumas county, Calif.; analyzed by Hillebrand and Steiger. (*Ibid.*)

5. Gabbro: east of Penman Peak, Calif.; analyzed by Hillebrand and Steiger. (*Seventeenth Annual Report*, Part I, p. 642.)

Summary of the evidence as to the origin of the green slates.—An attempt has been made to obtain evidence from three distinct sources as to the probable derivation of the green slates. One of these possible lines of solution gave no evidence of value; the other two, however, are apparently conclusive.

[1] *Fourteenth* and *Seventeenth Annual Reports*, U. S. Geological Survey.

1. The structural relations of the green and the black slates seem to prove that the green slates are derived, by dynamic metamorphism, from an igneous rock; further, that this rock was an intrusive massive rock, not an interbedded tuff; and that it was intruded into the Mariposa slates at some period subsequent to their deposition, but before their assumption of slaty cleavage.

2. Microscopic evidence, though inconclusive owing to the lack of a sufficient supply of material, proves that the green slates are composed of thoroughly crystalline material. The rock forming one of the nearby dikes is shown to be a gabbro.

3. Chemical analyses of the green slates show that they are widely different in composition from the black slates, and, indeed, from any normal clay slate. Comparison of the same analyses with those of igneous rocks of the region show striking similarities in composition between the green slates and certain massive, basic, igneous rocks—gabbros and allied rocks.

There are, of course, no reasons why an igneous rock should not be susceptible of change, under proper conditions, into a roofing slate; and the possibility of such a change occurring would probably have been conceded by most geologists, had the question been brought to their attention, before the foregoing description of an actual occurrence had been published. Notwithstanding these facts, the California occurrence seems to be unique. The extensive literature of roofing slate has been examined by the writer, so far as this literature is available, and no similar occurrences of the derivation of roofing slates from massive igneous rocks have been noted. More than this, the possibility of such an occurrence would seem to have been overlooked by most writers, who either expressly or by implication use the term "roofing slate" to include only argillaceous sedimentary rocks. This oversight is the more inexcusable, because a large industry has been based for a century or more, in one English district, on roofing slates derived from tuffs.

Utilization of the green slate.—While the green slate does not occur in a body of sufficient thickness to be worth quarrying for itself alone, it is a resource of considerable value as it is at

present exposed in the quarry of the Eureka Slate Co. With the exception of the usual decomposed material near the ground surface, the green slate dike furnishes merchantable slate from the outcrop down to the tunnel level.

The green slate splits readily, though not with as smooth a surface as the black slate; and gives a pleasant color contrast when used for trimming or lettering on black slate roofs. It bears punching and countersinking very well, and is sufficiently strong for roofing use.

Compared with the large amount of merchantable black slate now in sight, the total quantity of green slate is so small that no attempt is being made to push its sale for use separately from the black slate. It is now supplied solely as an ornamental trimming for black slate roofs, for lettering, and similar uses.

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ON THE CHEMICAL COMPOSITION OF AMERICAN SHALES AND ROOFING SLATES.

In the preceding paper the statemeut is made that the analyses of the green slates at Slatington, Calif., "differ widely from those of any normal clay slates." So little attention is paid to the composition of sedimentary rocks, as compared with that of igneous rocks, that the truth of this statement may not be obvious to all readers. The present paper has been prepared partly for this reason, but more largely because a summary of our present knowledge of the subject seems desirable.

Thirty-six analyses of American roofing slates have been compared and used in the preparation of an average. These analyses include all the published records noted by the writer in the course of an examination of the literature, together with several unpublished analyses obtained from the records of the chemical laboratory of the U. S. Geological Survey. The writer's acknowledgments are due to Dr. F. W. Clarke and Dr. W. F. Hillebrand for aid in this work.

Geographical distribution of the slates.—The thirty-six analyses of slate discussed in this paper represent material from eleven states, representing twelve distinct slate-producing districts. While this geographic distribution is fairly representative of the present condition of the slate industry in the United States, it is by no means representative of the available supply of good material; for, of the twelve states from which analyses are on file, ten are states of the Atlantic seaboard, or closely adjacent thereto. Utah and California furnish the remaining analyses. This distribution is due to purely commercial causes, which have prevented the exploitation of equally good material located in other states, but without transportation facilities or markets. To this extent, therefore, the analyses are not as representative of a given type of material as one might wish.

Geologic distribution of the slates.—Owing in large part to the geographic distribution of the analyses, the geologic distribution

has no very wide range. This is due to the fact that in the Atlantic states, which, as above noted, furnish the bulk of the analyses, the true roofing slates are practically confined to the formations below the Medina. Two exceptional instances are represented in the series of analyses. One is a highly metamorphosed slate of doubtfully Carboniferous age; the other is a rather soft slate of undoubted Upper Devonian age. With the exceptions of these two eastern slates, and of the Jurassic slates of California, the analyses represent merely the Ordovician, Cambrian, and, doubtfully, pre-Cambrian. The table below gives the geologic distribution of the analyses in detail:

Age	Number of Analyses
Jurassic	1
Carboniferous?	1
Devonian	1
Upper Silurian	0
Ordovician	11
Cambrian	16
Pre-Cambrian, Cambrian, or Ordovician	6
	36

TABLE I.

RESULTS OF THIRTY-SIX ANALYSES OF AMERICAN ROOFING SLATES.

	Number of Determinations	Maximum	Average	Minimum
Silica (SiO_2)	33	68.62	60.64	54.05
Alumina (Al_2O_3) + titanic oxide (TiO_2)	32[1]	24.71	18.05	9.77
Ferrous oxide (FeO)	19	6.81	3.66	0.97
Ferric oxide (Fe_2O_3)	19	7.10	2.25	0.52
Total iron oxides (FeO + Fe_2O_3)	33	10.66	6.87	2.18
Lime (CaO)	34	5.23	1.54	0.00
Magnesia (MgO)	34	6.43	2.60	0.12
Potash (K_2O)	26	5.54	3.69	0.72
Soda (Na_2O)	26	3.15	1.19	0.20
Total alkalies (K_2O + Na_2O)	29	8.68	4.74	1.93
Pyrite (FeS_2)	18	.....	0.38	
Carbon dioxide (CO_2)	16	.....	1.47	
Water of combination	15	.....	3.51	
Moisture, below 110° C	16	.....	0.62	

[1] In nineteen of these, titanic oxide was separately determined, though it has here been included with the alumina. The average of these nineteen determinations gave 0.73 per cent. TiO_2.

Average chemical composition of American shales.—In *Bulletin 168*, U. S. Geological Survey, on pp. 16, 17, Dr. Clarke has quoted a series of composite analyses of American sedimentary rocks. The material was selected and the samples were prepared by Mr. G. K. Gilbert, assisted by Mr. G. W. Stose, and the analyses were made by Dr. H. N. Stokes in the chemical laboratory of the Survey.

These composite analyses, so far as they relate to shales, are reprinted here as Table II. The determinations of a number of minor constituents are omitted. In this series each individual shale was taken in amount roughly proportional to the mass of the formation which it represented. The samples were then mixed into one uniform sample from which, by a single analysis, an average composition was determined.

In column 1 is given the result of an analysis of twenty-seven Mesozoic and Cenozoic shales; and in column 2 that of fifty-one Paleozoic shales. Column 3 gives the average of these two determinations, giving them, respectively, weights as 3 to 5. The values in this column are, therefore, an approach to the "average shale" composition.

TABLE II.

COMPOSITE ANALYSES OF AMERICAN SHALES.

	1	2	3
Silica (SiO_2)	55.43	60.15	58.38
Alumina (Al_2O_3)	13.84	16.45	15.47
Titanic oxide (TiO_2)	0.46	0.76	0.65
Ferrous oxide (FeO)	1.74	2.90	2.46
Ferric oxide (Fe_2O_3)	4.00	4.04	4.03
Lime (CaO)	5.96	1.41	3.12
Magnesia (MgO)	2.67	2.32	2.45
Potash (K_2O)	2.67	3.60	3.25
Soda (Na_2O)	1.80	1.01	1.31
Carbon dioxide	4.62	1.46	2.64
Water of combination	3.45	3.82	3.68
Moisture, below 110° C	2.11	0.89	1.34

It may be noted in passing that some of the differences in composition between the Paleozoic and the later shales were, either in degree or in kind, contrary to what might have been expected, from a purely theoretical standpoint. The writer is

at present inclined to believe that these unexpected results are susceptible of a rational, though decidedly novel, explanation. In case this belief is supported by the results of investigations now in progress, this explanation will be presented in a later paper.

Comparison of "average slate" and "average Paleozoic shale" analyses.—As thirty-five of the thirty-six slate analyses are of Paleozoic material, the "average slate" will obviously be comparable most directly with the composite analysis of the fifty-one Paleozoic shales. The necessity for restricting the comparison in this manner is accentuated by the fact, above intimated, that the Paleozoic and the later shales are not themselves directly comparable.

The average slate contains 60.64 per cent. of silica, as against 60.15 in the Paleozoic shale. Alumina and titanic oxide together amount to 18.05 per cent. in the slate, and to 17.21 per cent. in the shale, the titanic oxide being practically the same in both.

While the proportions of ferrous and ferric iron oxide in the slate and shale are reversed, the *total* amount of iron oxides is very close, being 6.87 in the slate and 6.94 in the shale. The lime and magnesia show the first interesting difference, and this is but slight. While their ratios are closely alike in the two rocks ($\frac{MgO}{CaO}=1.688$ in the slate, and 1.646 in the shale), the total lime and magnesia in the slate is 4.14 per cent., and in the shale 3.73 per cent. A somewhat similar case occurs with the alkalies. Here $\frac{K_2O}{Na_2O}=3.101$ in the slate, and 3.564 in the shale; while the total alkalies amount to 4.74 and 4.61 per cent. respectively.

The variations in carbon dioxide, water of combination, and moisture are so slight that they would not appreciably affect the percentages of the other constituents, with the exception of silica and alumina.

Summary of results.—The results of the comparison are mainly negative, but they are of value even in that way.

The average slate is practically identical in composition with

the average shale. It contains *slightly* more of certain readily soluble constituents than does the average shale. This is to be accounted for by the fact that the slate is, on the whole, made up from finer materials than the shale; if it were otherwise, its cleavage would not be so perfect. During the change from shale to slate—or from mud to slate—its composition, omitting water from consideration, was practically unaltered. The only effect of metamorphism was the assumption of slaty cleavage, and this was effected without the introduction of any new constituent.

Incidentally, the statement in the preceding paper, that the green slate from Slatington, Calif., differs in composition from any normal clay slate, is entirely justified.

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ARAPAHOE GLACIER IN 1903.[1]

A VISIT to Arapahoe Glacier, in the cirque on the east side of Arapahoe Peak, west of Boulder, Col., in 1903, for the purpose of comparing its present condition with that existing at the time of the preceding examination, brought to light some interesting and important facts. In 1902 we were on the ice on three different days during the last week of August. In 1903 the visit was made on September 2, only one day being spent on the ice by the writer, in company with Professor A. H. Felger, of Denver. The summer of 1902 was particularly favorable for our first visit because the high temperature and preceding shortage of precipitation had caused the snow to melt from the surface of the entire glacier up to the Bergschrund, which was exposed as a great, gaping break clear across the face of the glacier; but in 1903, even at a great distance, it could be seen that snow still remained on the ice down to the main system of crevasses, while the Bergschrund was exposed for only a very short distance, which was perhaps due as much to the unusually cool spring and summer as to the greater fall of snow last winter. The greater part of the Bergschrund and many of the visible crevasses were partly or wholly filled with last year's snow, though in some cases the snow merely formed a bridge instead of filling the crevasse, which made it dangerous traveling above the line of uncovered ice.

On the whole, there was a slight increase in the height of the snow and ice along the north side and in the height of the ice along the terminal moraine, but at two points along the terminal moraine there has been a decided shrinkage during the year, which is of some importance. One such point is at the lake retained by the moraine, or rather where the central surface drainage system pours its waters into the lake, which is shown on the map (Fig. 2) and the photograph (Fig. 8) accompanying

[1] For a general account of this glacier see this JOURNAL, Vol. VIII, p. 647. For a more detailed account see Vol. X, p. 839.

Dr. Fenneman's paper. The other point of shrinkage is where the western surface drainage breaks through the moraine. Both of these ice valleys were greatly deepened, and their sides were much steeper than last year, which suggests stream erosion as the prime cause of the change in the face of the glacier at these points. However, as the surface streams flow southward, and their valleys are consequently exposed to the full glare of the noonday sun and protected from cooling breezes, the confinement of heated air in the valleys is an element to be reckoned with in the problem of waste at these points. These surface streams on the front of the glacier are made possible by the fact that for some distance back from the terminus the ice is free from open crevasses into which the water arising from surface melting could otherwise plunge. Wasting at these points, while apparently gaining slightly, or at least fully holding its own, at other points along the front of the glacier shows clearly how a glacier may change the shape of its terminus, and consequently of its terminal moraine, as shown by the accompanying diagram. It is probable that the confusion of moraines several miles below the present terminus of Arapahoe Glacier, where they intersect each other at all angles, is partly due to the rapid and repeated changes in the end of the former ice tongue, as well as partly to the melting out of ice blocks in the moraine, as suggested by Dr. Fenneman.

FIG. 1—Diagram on exaggerated scale, the broken line showing change in front of glacier now apparently in progress, from erosion and melting along water courses.

Where the surface stream enters the terminal lake the ice is now worn to the ground moraine, so that the water issues from

beneath the ice at the upper edge of the lake loaded with rock flour, and rises milky white abruptly through the clearer water gathered from the surface, forming a striking feature not found there in 1902, when, if it found its way into the lake at all, it was so diluted before reaching the surface that it did not attract attention.

As would be expected from the deepening of the drainage valley leading into the lake, by vertical erosion, and the increase in its width by lateral erosion and melting, the area of the lake is much greater than in 1902, just as its area in 1902 was apparently greater than when examined by Professor Lee in the summer of 1900.

Another noteworthy fact is that almost the entire front of the glacier was steeper in 1903 than in 1902, upon which subject more data and accurate measurements seem necessary before a satisfactory reason may be assigned for the change.

Although the rate of flow for this glacier is unknown, it must surely be so slow as to require several years of normal or excessive precipitation or low temperature for its down-stream extension to recover from the effects of rapid waste during a series of warm, dry seasons.

An analysis of the records of the Denver, Boulder, Sugar Loaf, Moraine, and Long's Peak stations, as shown by the monthly statements of Mr. F. H. Brandenburg, Denver forecast official and section director of the Weather Bureau, indicates that from September 1, 1901, to September 1, 1902, the precipitation was far below normal and the average temperature was much above normal. On the other hand, from September 1, 1902 to September 1, 1903, precipitation was considerably above normal and average temperature was much below normal. The highest of these stations is only 8,500 feet above sea-level, and the nearest is about ten miles distant, so the figures given for the stations would not exactly apply to the glacier, the altitude of which is about 13,000 feet; but the fact that all the stations record greater precipitation and lower temperature for the latter period than for the former period makes it appear exceedingly probable that the same condition would have been shown if a rec-

ord had been kept at the glacier itself. Furthermore, the cirque containing the glacier is in full sight from the brow of University Hill in Boulder, and during the autumn of 1902, winter of 1902–3, and spring of 1903, the writer watched the peak as closely as possible, and was much impressed with the frequency with which clouds gathered in the glacial amphitheater when all was clear elsewhere. The snows began early in September and continued until late spring.

It seems possible that the significance of the silt on the morainal bowlders in 1902 may have been misunderstood, as a similar condition was observed in 1903; and yet it is hardly possible that the glacier flowed out over the moraine and then melted back to the base of the moraine between September, 1902, and September, 1903. A possible explanation suggests itself. The accumulation of snow on the glacier each year is known to be enormous, a great many feet in depth. The westerly gales are known to carry from the rim of the cirque to the glacier large quantities of dust and finely comminuted vegetable matter during every dry, windy period, which periods are common in that region and at that altitude. The accumulated snows containing such dust and vegetation cover the moraine to a great depth in winter. As the snow melts in the spring, the débris gradually accumulates at lower and lower levels, until finally it is left as silt on the tops of the bowlders and all over the moraine. Unfortunately, we brought none of it with us, and failed to make a minute examination of it under a good lens. The cause may be sufficient to account for the phenomena, but the subject is worthy of more extended investigation before announcing definite conclusions.

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THE APPALACHIAN RIVER *VERSUS* A TERTIARY TRANS-APPALACHIAN RIVER IN EASTERN TENNESSEE.[1]

In a very able and interesting paper, entitled "Geomorphology of the Southern Appalachians," by Hayes and Campbell,[2] considerable evidence is adduced in support of the theory that the drainage of the southern Appalachian valley up to late Tertiary time was through one rather large subsequent stream, occupying, in general, the position of the upper Tennessee and Coosa Rivers. This river, which ran down, as they believe, east of Lookout Mountain, over what is now the Tennessee-Coosa divide, and directly into the Gulf, has been called by them the Appalachian River. The evidence given for the existence of such a river is threefold:

"(1) the perfectly base-leveled divide between the Tennessee and Coosa River basins; (2) a comparison of the volume of material eroded from the Appalachian valley with that of the Tertiary sediments in central Alabama; and (3) the immaturity of the Tennessee gorge through the plateau below Chattanooga.[3]

The three lines of evidence will be taken up in the order given above and examined briefly in the light of other facts furnished by this region, to see if the Appalachian River theory is the most tenable.

The Coosa-Tennessee divide.—It is admitted by Hayes and Campbell that similar low divides are found between other river basins of the Appalachian valley from Pennsylvania southward; as between the Potomac and the James, and the James and the Roanoke; but they do not believe that any great river ever flowed

[1] The writer came to the view advocated in this paper in 1896, while engaged in the field under discussion. The paper was written in May, 1897 as a report in a course in physical geography in Harvard University given by Professor W. M. Davis. Publication has been delayed owing to a desire to make a more extended study of the problem in the field, but interest in other fields renders the making of such an examination improbable at an early date; it therefore seems best to present the paper in its original form.

[2] C. Willard Hayes and Marius R. Campbell, "Geomorphology of the Southern Appalachians," *National Geographic Magazine*, Vol. VI, pp. 63–126.

[3] *Ibid.*, p. 109.

over those divides. The Coosa-Tennessee divide is, however, wider and if peneplained by backward-cutting small streams, those streams, they believe, should have a "dendritic inosculating" arrangement.

By referring to the structural sheet of the "Ringgold Folio" of the *United States Geologic Atlas*, it will be seen that the width of the Coosa-Tennessee divide is easily explained by the structure of the region. The floor of this valley is almost entirely of Knox dolomite and a Cambrian shale both tilted at various angles, and always valley-making. It seems quite clear that, throughout this region, topography depends upon structure rather than upon the size of the streams. The width of the Coosa-Tennessee divide is limited only by the conglomerate- and sandstone-capped strata approaching horizontality. On the east, the resistant capping is Silurian; on the west, Carboniferous. A great river is evidently not necessary for the base-leveling of a region composed of the upturned dolomite and shales of this region. Cade's, Ware's and Tuckaleechee coves,[1] east of Chilhowee Mountain, are examples of this. The floors of these coves are of deformed dolomite and Wilhite slate, a very calcareous slate, and are lowered as rapidly as the streams can cut down their channels through the Chilhowee sandstone. These coves are surrounded by massive conglomerates, sandstones and slates, and the streams which drain them have their sources practically within the coves.

Dendritic branching of streams could hardly be expected in a region where the beds are varied in character (alternating harder and softer) and at the same time deformed into structures approaching parallelism, as these have been in this part of the Appalachian valley. Considering the structure and elevation of the region, it is difficult to conceive how the stream habit could be other than it is.

The volume of material eroded and deposited.—This evidence favoring the Appalachian River theory is briefly as follows: A stream occupying, in general, the present position of the Coosa-Alabama River is held responsible for the late Cretaceous and

[1] "Knoxville Folio," *U. S. Geologic Atlas.*

Tertiary sediments (Ripley, Lignite, Buhrstone, Claiborne, and White limestone) deposited in an area, limited on the east by a line midway between the Alabama and the Chattahoochee, and on the west by a line similarly drawn between the Alabama and the Tombigbee Rivers; sediments that occupy an area of 6,500 square miles and a volume of 2,340 cubic miles. The volume of material carried away from the basin of the Alabama and its tributaries between the Cretaceous and Tertiary peneplains is about 622 cubic miles; but if we add to this the volume carried from between the two peneplains in the upper Tennessee valley, the total amounts to 2,500 cubic miles.

If it be admitted that the only source of the Cretaceous and Tertiary sediments in the area named was from between the Cretaceous and Tertiary peneplains in the two river basins, and that this detritus was carried out in the direction named, the evidence is conclusive that the Appalachian River was a reality. But from the character of the coastal plain beds in this particular area, it is doubtful if the Alabama River, or its ancestor, should be held wholly responsible for the strata lying along its lower course. At least one-third of the thickness of these beds shown in outcrops is of limestone, bearing quantities of corals and other fossils.[1] The Alabama River cannot be held accountable for those deposits transported in solution or in a very finely divided state to the exclusion of the other rivers emptying into the Mississippi embayment. After the formation of the Nita crevasse in 1890, fine mud from the Mississippi River was deposited in Mississippi Sound even up to the mouth of Mobile Bay, driving out the fish and killing the oysters.[2] The thickest and most important of the beds attributed to the Appalachian River, the Lignitic (900 feet), is composed of cross-bedded sands and clays, and would seem, at first sight, more than all others, to have been deposited by this river; but a study of the whole area shows that this formation increases in thickness and in coarseness toward the west, in western Alabama and in Mississippi; while

[1] EUGENE A. SMITH, L. C. JOHNSON, AND DANIEL W. LANGDON, JR., *Report on the Geology of the Coastal Plain of Alabama* (1894), pp. 107 ff.

[2] *Ibid.*, p. 30.

east of the Alabama River it is very calcareous and "inconspicuous,"[1] showing that these sandy sediments were brought down from the west instead of from the north. Considering the nature and disposition of these sediments, and the decided notch in the Continental shelf nearly opposite Mobile Bay, and the tendency of the Gulf current to carry sediments eastward in this region, there seems no reason for believing that the Coosa-Alabama River was ever larger than it is at present.

Character of the gorge below Chattanooga.—It is claimed that this gorge is too immature to have been the channel of the Tennessee since Cretaceous time, or during the erosion of the upper Tennessee valley. It is admitted that erosion has progressed much more rapidly on the upturned strata of the valley, but it is thought impossible that the river could make so wide a valley along one part of its course and be held within such narrow limits lower down.

The rate of erosion in tilted soluble rocks, compared to that in horizontal beds of the same nature, capped by heavy beds of sandstone and conglomerate has never been definitely determined; but the contrast is undoubtedly strong. The Nashville basin has been eroded in strata only slightly domed, while the streams leading therefrom pass through gorges in horizontal strata having only a slight siliceous covering. It is a notable fact, in this connection, that the valley of the upper Tennessee is eroded back toward the west only just to the beginning of the horizontal strata, and where the horizontal strata have been reached the slope is as steep and the distance cut into the horizontal beds is no greater than in the Walden gorge; and moreover, the streams that run from the Walden plateau east into the great valley have proportionally as narrow gorges with as steep slopes as has the Tennessee in its gorge. If the Appalachian River existed and the valley is older than Walden gorge, these side gorges are also older, and, according to this reasoning, should be wider; for the streams, although small, apparently carry all the waste brought to them. The wide coves on the eastern side of the valley made by small streams on upturned dolomite, and pre-

[1] *Ibid.*, p. 148.

sumably of the same age as the gorges on the west, have already been noted.

It appears, then, that evidence favoring the existence of the Appalachian River is small, although this has been the view of some observers for more than twenty years. Long,[1] in his report of the survey of the Tennessee and Holston Rivers in 1875, states this as his view, but gives little evidence for its support.

A trans-Appalachian river.—What seems to the writer a more tenable view of the history of the drainage of this part of the Appalachian province follows. Up to the close of Cretaceous time the rivers flowed off toward the northwest from the axis of the Great Smoky Mountains, or in general, at right angles to this axis; and the more nearly base-leveled the Cretaceous peneplain became, the more the streams meandered upon it. The headwaters of these old rivers, which cut directly across the strike of the present valley strata, are now represented by the Doe-Watauga, Nolichucky, French Broad, Big and Little Pigeons, Little River, Little Tennessee, upper Tellico, Hiwassee, Ocoee, and upper Connasauga. After the uplift of the Cretaceous peneplain, by differential erosion the great valley began to be formed, and lateral subsequent branches pushed their way back along the strike of the valley-making strata. The uplift being greater in the northern part, the south-flowing subsequent streams, being the more accelerated, have cut back more rapidly than those flowing toward the north, and have made practically all the captures in this region. This process of capturing has gone on until now all the original transverse streams have been turned from their courses across the Cumberland plateau southward into the Tennessee River, which alone maintains its course across the Walden plateau. The upper course of the original Walden gorge river has already been taken south by the Connasauga, while the Tennessee awaits a friendly pirate to conduct it south directly into the Gulf through a shorter and easier course. That the position of the master stream has been west of Lookout Mountain rather

[1] Lieutenant-Colonel S. H. Long, "Report Relative to the Improvement of the Navigation of the Holston and Tennessee Rivers," *House Executive Document*, Forty-Third Congress, Second Session, Vol. XV, No. 167, p. 16.

than east of it for a long period is indicated by the westward drainage on Walden plateau south of the gorge. The character of the Tertiary sediments in Alabama, as pointed out on a previous page, indicates that the larger streams entered the Mississippi embayment west of the Alabama River. The mature swing of Walden gorge also suggests that the course of the river was established here when the region was nearly at base-level, previous to the uplift of the Cretaceous peneplain.

A consideration of the failure to find any satisfactory process by which a stream, when once established in this easily eroded valley and flowing directly into the sea, could be diverted across Walden's Ridge, together with the foregoing facts, renders the existence of a Tertiary river across the present valley and along the course of Walden gorge more probable than that of a Tennessee-Coosa, or Appalachian River.

CHARLES H. WHITE.

THE CONTACT OF THE ARCHÆAN AND POST-ARCHÆAN IN THE REGION OF THE GREAT LAKES.

THE accompanying map has been compiled from one published by the Geological Survey of Canada, to which was added the Adirondack region from one published in Van Hise's *Pre-Cambian Geology.* "Archæan" is used to include the Huronian and Laurentian, as originally proposed by Dana. It does not here include the Animikie or Keweenawan, which are considered post-Archæan. With this exception, Archæan is here used as the equivalent of the pre-Cambrian of many writers.

The purpose of this paper is to bring out the peculiar step-like arrangement of the contact between the Archæan and post-Archæan in the region of the Great Lakes. This is shown clearly on the map, where a heavy line has been drawn to emphasize this feature. The contact is further marked by the almost universal elevation of the Archæan several hundred feet above the succeeding formations.

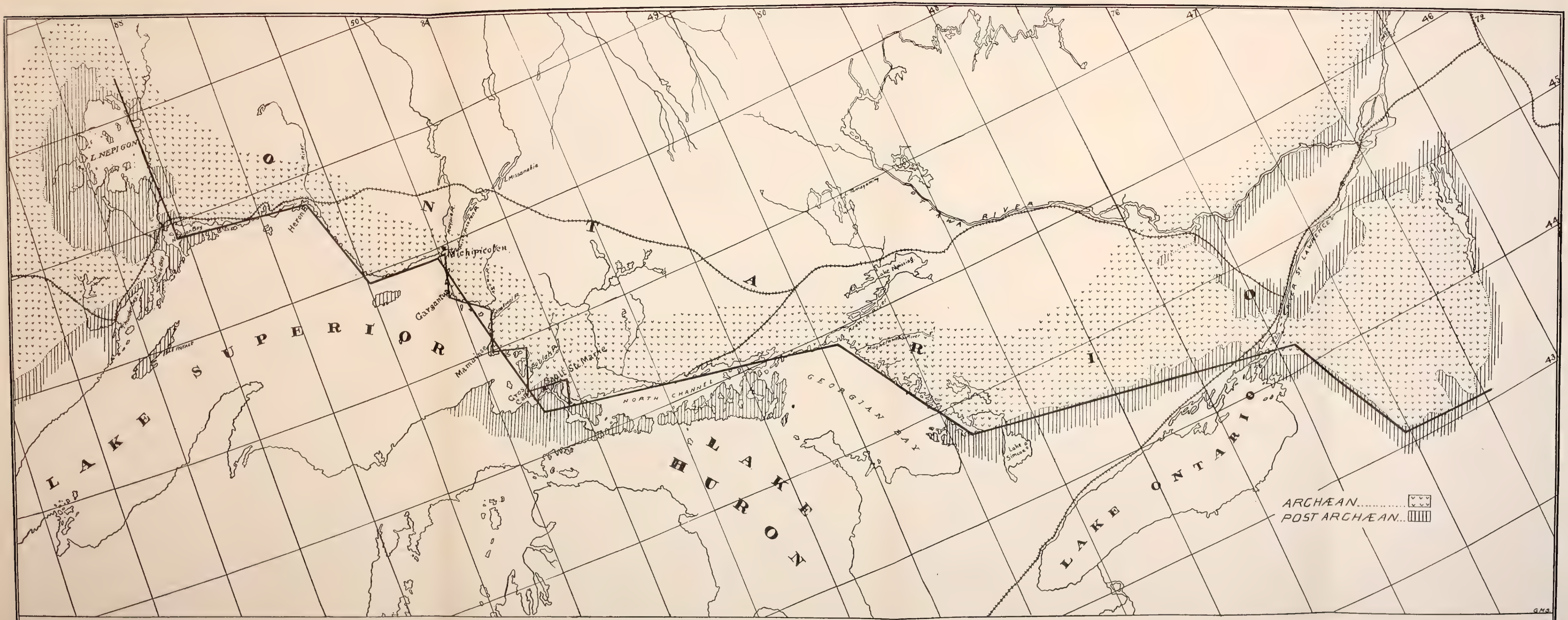
Beginning at the St. Lawrence on the east, we find the line of contact runs about 10° N. of W. to the southeastern corner of the Georgian Bay. The Archæan fronts the Paleozoic sediments nearly always as a hill rising one hundred or more feet above them. It is true the Archæan underlies the sediments, and perhaps as a fairly regular plain, but it would seem that there has been some disturbance by which a part of the Archæan has been relatively depressed. The contact of the Paleozoic follows closely this line of movement covering the lower part and abutting against the higher.[1]

The east shore line of the Georgian Bay runs 30° W. of N., and this may be taken as the line of contact. Only in the southeast corner do post-Archæan rocks appear. The Archæan rises in hills a few hundred feet above the water line.

The contact north of Lake Huron again runs 10° N. of W.

[1] Compare WILSON, JOURNAL OF GEOLOGY, Vol. XI, p. 651 ff.


OTTAWA RIVE
R
BAY
Lake Simcoe
KES REGION



GEOLOGICAL MAP OF THE GREAT LAKES REGION

As before, the Archæan hills rise several hundred feet above the waters of the lake, and the post-Archæan sediments abut against them at the water's edge.

The general direction of the shore line from Sault Ste. Marie to Michipicoten is 15° W. of N. It is, however, not so regular as other parts of the coast. At Gross Cap, Mamainse and Gargantua the Archæan projects to the west in three sharp teeth with deep bays between. At each point there occurs a small area of Keweenawan rocks lying almost flat and rising but little above the waters of the lake. The Archæan hills rise, on the contrary, almost vertically for several hundred feet, and at a few miles from the shore reach as much as 1,200 feet. The line of dislocation in this region is not straight. but serrate. The general direction of all the north-bearing lines is, however, preserved.

From Michipicoten the shore line trends due west, rising in steep, precipitous hills. No post-Archæan sediments are found in contact with the Archæan, but Michipicoten Island of Keweenawan age is only a few miles south.

From the mouth of the Pucaswa River the shore line bears about 18° W. of N., having the same high, precipitous Archæan cliffs, and with no post-Archæn sediments above water level.

From Heron Bay the shore line again bears about 10° N. of W. as far as Nipigon Bay. Archæan hills rise perpendicularly several hundred feet above the lake. In Nipigon Bay Keeweenawan sediments appear, with interbedded lava sheets, the whole rising several hundred feet above the level of Superior.

The contact here turns again to the north, but on the map does not appear to be so definite. The Archæan hills do not rise in vertical cliffs along the eastern shore of Lake Nipigoan, and in consequence the lava flows of the Keweenawan, having no definite walls to impinge against, spread out in irregular bays. The east shore of Lake Nipigon is prolonged into a deep, narrow bay at the south, and from this a valley leads through to Lake Superior, which is believed by Parks to be an old outlet of the lake. This valley and bay are in direct line with the east shore of Lake Nipigon and are taken to represent the counterpart of the coast lines described in earlier paragraphs. The Archæan to

the west of the line is much lower than that to the east of it, and is separated from it by a deep valley. The Keweenawan to the east of the line on Lake Nipigon is a shallow overflow. The physical features of this line are thus similar to the others, but with the characters less marked, due probably to the fading out of the force-producing dislocation.

Eastward from the St. Lawrence the contact seems to run 25° S. of E. and then east. With this region I am not personally familiar, but believe that here also the Archæan rises in steep hills above the adjoining, low-lying post-Archæan.

The two facts brought out above, viz., the step-like regularity of the lines of contact, and the difference in altitude of the rocks of the two periods, can be best explained, I believe, by assuming a dislocation in the Archæan before the deposition of the post-Archæan sediments. The southern part was depressed and probably changed in inclination, as suggested by Wilson in the paper quoted above. Sediments were deposited over this depressed part and abutted against the cliffs of the northern part. They also extended into the deeper valleys of the northern part. Perhaps even a considerable portion of the northern part was thinly covered, but, if so these rocks have since been removed.

The regularity of the dislocation extends from longitude 75° to longitude 88°, and from latitude 43° to latitude 50°, or for 700 miles by 500. For the greater part of the distance this line of fracture forms the northern and eastern shores of Superior and Huron.

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SAULT STE. MARIE, CANADA.
January 21, 1904.

THE RELATIONSHIPS AND HABITS OF THE MOSASAURS.

There is, at present, no group of extinct reptiles which is better known than that of the mosasaurs or pythonomorphs; there is no group concerning whose affinities and relationships there have been more discussion and differences of opinion; and, also, the writer may venture to add, there is no group of extinct vertebrates concerning whose phylogeny and taxonomic position there is now less ground for dispute. The mosasaurs are specialized aquatic lizards, descended from the immediate ancestors of the modern monitors, through the extinct aigialosaurs, and which became wholly extinct near the close of Cretaceous time. They belong among the Lacertilio and are more nearly related structurally and phylogenetically to the living monitors than are the monitors to the living amphisbaenas or chameleons.

Whether the Squamata are an order, as is usually taught in text-books, a superorder, as Fürbringer and Osborn suggest, or a subclass, as Gadow believes, scarcely affects the relations of their component parts, nor the value of the group as a whole, if all the other so-called orders of reptiles are raised to equal rank. But to make the Squamata a superorder, as does Osborn in a recent publication,[1] while leaving far more specialized groups, such as the pterodactyls or turtles, in their former ordinal positions, is manifestly inconsistent. I know not what may be the object of taxonomy unless to indicate the relative degrees of divergence or of specialization of organisms; and to separate the scaled reptiles from the Rhynchocephalia by superordinal characters, while the far greater differences between the pterodactyls and other reptiles, for instance, are accorded an ordinal value only, is, in my opinion, unjustifiable. Nor can it be said that the differences between a lizard and a snake have nearly as

[1] *Memoirs of the American Museum of Natural History*, Vol. I (N. 1903), p. 456.

much value as those between any other two groups of reptiles properly called orders.

That the classification of the vertebrates will some time reach a fairly satisfactory stability is certain, but that this much-wished-for consummation is not at the present time a reality is painfully evident. Especially is the lack of a taxonomic equilibrium between the various groups of reptiles and those of the birds very apparent. In every group of organisms, where individuals and species are abundant, there is a constant, an almost unchecked, tendency to raise the lower divisions to a higher rank, without due regard to their relative values, so far as those of other groups are concerned; and this tendency will never be discouraged save by the general morphologist; the specialist usually lacks that breadth of view so necessary for a proper perspective. The ornithologists, especially, have been in the past a law unto themselves in this respect, without due fear of the results of their taxonomic misdeeds before their eyes. Twenty-five or thirty groups of birds have been given ordinal rank, while it seems evident that the whole class scarcely presents as many or as wide internal differences, unless it be in a few forms, as are found in not a few single groups of reptiles that are usually called orders. But, I respectfully submit, the raising of the orders of reptiles to subclass rank, as Gadow has done, is not the proper solution of this difficulty. Unless we invent superclasses and superkingdoms, or some entirely new classificatory denominations, an impassable wall will soon be reached, when all the orders are leveled up to subclasses, and we are no nearer a final symmetrical classification than we were, though there may have been many excellent opportunities for coining new names.

The relationship of the mosasaurs to certain modern lizards, the Varanidae, was pointed out by Cuvier in his original description of the famous Maestrichtian example one hundred years ago. Goldfuss, Owen, and Marsh all recognized this relationship as a real one, and refused to give to these animals the rank which Cope insisted upon giving. It was Baur, however, who first strongly emphasized the importance of their varanid affinities. He gave to the mosasaurs only a family rank

in the superfamily Varanoidea; perhaps an extreme view, but one which more recent discoveries have, I believe, in large measure substantiated. Gadow, very recently, has gone to the opposite extreme in separating the mosasaurs into a distinct subclass away from the subclass Squamata. Cope, notwithstanding his wide acquaintance with living and fossil reptiles, urged that their ophidian affinities were stronger than their lacertilian ones. Baur believed them to be only specialized and modified varanids; while Osborn has failed to see any marked varanid affinities in them, even suggesting that they did not arise from the same common stem.

In 1892 Kramberger-Gorjanović[1] described from the Lower Cretaceous (probably Gault) of the island Lesina, near the Dalmatian shores of the Adriatic, the remains of a remarkable lizard, which he called *Aigialosaurus*. While his figures have recently been shown to be incorrect in some details, and while some of his minor interpretations were manifestly wrong, he correctly assigned to his new genus and its allies an intermediate position between the true Varanidae and the Mosasauridae, suggesting that they had descended from the Varanidae and were ancestral to the Mosasauria, while from them had been derived the dolichosaurs as a side branch.

> Aus unseren Betrachtungen aber folgt ganz unzweideutig, dass man die erwähnten fossilen Gattungen weder der Familie Varanidae, noch direkt den Pythonomorpha zutheilen kann. Sie sind einergemassen Collectivtypen, welche an sich Merkmale zweier Unterordungen u. zw. der Lacertilia und Pythonomorpha tragen, ... eine Uebergangsgruppe zwischen die Unterordnungen Lacertilia und Pythonomorpha zu stellen ist.

His conclusions regarding the relationships of the Mosasauria are the more creditable from the fact that the only information available to him at that time concerning them was incomplete, and in part erroneous. Nevertheless, so apparent were they that both Boulenger and Dollo accepted them, recognizing in *Aigialosaurus* an ancestral type.

More recently, Kornhuber[2] has described and figured, in an

[1] "Rad" der südslavischen Akademie der Wissenschaften und Kunst (Agram), Vol. CIX, pp. 96–123; Plate I, ff. 1, 2; Plate II, ff. 1, 2, 4.

[2] *Abhandlungen der k.-k. geologischen Reichs-Anstalt zu Wien*, 1901.

excellent way, the remains of another lizard from Lesina, closely allied to *Aigialosaurus*. So evident were the relationships of his *Opetiosaurus* to *Varanus* that he was inclined at first to unite them in the same genus. Unfortunately Kornhuber was apparently ignorant of the recent publications by Merriam, Osborn, and the writer upon the mosasaurs. Had he been more familiar with the structure of the mosasaurs, I doubt not that he would have recognized more clearly their relationships, and would have detected certain wrong determinations, clearly apparent in his figures, and recognized by Nopcsa—the supraorbital, nasals, columella, etc. There is no supraorbital in the mosasaur skull.

To Nopcsa,[1] very recently, is due the credit for correctly estimating the value of the various annectant characters in these and the other known Cretaceous lizards. His views, though only amplifications and confirmations of those held by other writers, are supported by such undeniably forceful arguments that they cannot be gainsaid.

Aigialosaurus and *Opetiosaurus* especially, with other Lower Cretaceous lacertilians, were clearly in a direct ancestral line between the mosasaurs and the undoubted direct ancestors of the modern monitors, thus confirming Baur's views and disproving those of Osborn. These semi-aquatic lizards lived, evidently in abundance and in many forms, during the latter part of the Lower Cretaceous time, at least in southern Europe. The earliest mosasaurs of which we have any knowledge are probably those from the Cenomanian of New Zealand, and it is not at all improbable that their birthplace was somewhere near the Mediterranean Sea, at or near the close of the Lower Cretaceous. Dollo long ago expressed the opinion that the center of dispersion of the mosasaurs was somewhere in the vicinity of New Zealand, and his views were probably not far wrong. They reached northern Europe shortly after the beginning of the Upper Cretaceous, and North America before the beginning of the Senonian.

Aigialosaurus and *Opetiosaurus* especially—for they are closely

[1] *Beiträge zur Paleontologie und Geologie Oesterreich-Ungarns und des Orients.* Vol. XV (1903), Plates V, VI.

allied—so far as the structure of the skull is concerned, present a most striking resemblance to the mosasaurs, save perhaps in the absence of pterygoid teeth. They have the same peculiar form of the quadrate, similar teeth, similar frontal and parietal bones, nares, and, most remarkable of all, the same peculiar hinge in the lower jaws, unknown in other reptiles. Were the vertebræ and ribs to be found in the Kansas chalk unassociated with limb bones, they would almost without hesitation be referred to the mosasaurs. The hands and feet have the same strong resemblances in their form, but there is no hyperphalangy, a character but feebly indicated in some of the mosasaurs. In the elongated limb bones, and especially in the presence of a true sacrum, the real differences between these reptiles are seen. On the other hand, it is especially in those characters wherein they resemble the mosasaurs that they differ from the monitors. Like the mosasaurs, they have but seven vertebræ in the neck, a number found in no other scaled reptiles. It is very certain that they had webbed feet, though the claws had not disappeared.

That the varanids are a very old group, dating at least as far back as the Jurassic, seems highly probable, especially so in the light of the recent discovery of an iguanid lizard by Broom in the Karoo beds of South Africa. As was long ago shown by Boulenger, Beddard, and others, the Varanidae are an isolated group among modern lizards, distinguished not only in the structure of their skeleton, but also by many other characteristic differences in their anatomy.

In my opinion, there are no more striking examples of evolution presented in all vertebrate paleontology than that of the aquatic mosasaurs of the Upper Cretaceous, through the semiaquatic aigialosaurs of the Lower Cretaceous, from the terrestrial varanoids of the lowermost Cretaceous or Upper Jura.

That the snakes originated from the lizards much earlier than we have any definite knowledge would seem very probable. We have no certain evidence of them prior to the latter part of the Upper Cretaceous, that is, the Laramie; but, since it now seems almost certain that at least two distinct phyla of the lizards lead-

ing to modern forms had become well differentiated by the close of the Jurassic, or shortly thereafter, it is not at all unreasonable to suppose that the snakes had branched off as early as, or earlier than, the beginning of the Lower Cretaceous.

The relationships of the chief groups of the Squamata may be expressed as follows:

Order Squamata (Lepidosauria).
- Suborder Sauria (Lacertilia).
  - Superfamily Platynota.
    - Family Varanidae Gray. Pleistocene—recent.
      - Genus *Varanus* Merrem. India, Australia, Africa.
    - Family Dolichosauridae (Kramb.) Nopcsa. Cretaceous.
      - Genera: *Dolichosaurus* Owen, *Acteosaurus* Meyer, *Pontosaurus* Kramb., *Adriosaurus* Seeley.
    - Family Aigialosauridae (Kramb.) Nopcsa. Lower Cretaceous.
      - Genera: *Aigialosaurus* Kramb., *Carsosaurus* Kornh., *Opetiosaurus* Kornh., *Mesoleptus* Carnalia.
  - Superfamily Mosasauria.
    - Family Mosasauridae Gervais. Upper Cretaceous.
      - Genera: *Mosasaurus* Conyb., *Clidastes* Cope, *Platecarpus* Cope, *Tylosaurus* Marsh, *Baptosaurus* Marsh, *Plioplatecarpus* Dollo. *Hainosaurus* Dollo, *Prognathosaurus* Dollo, *Phosphorosaurus* Dollo, *Brachysaurus* Williston.
  - Superfamily Kionocrania (true lizards). Trias — recent.
  - Superfamily Amphisbaenia. Oligocene — recent.
  - Superfamily Rhiptoglossa (chameleons). Recent.
- Suborder Serpentes (Ophidia). Laramie Cretaceous — recent.

It is a remarkable fact, for which there has never been any adequate explanation, that the mosasaurs are wholly unknown in the juvenile condition. Altogether, throughout the world, more than three thousand specimens of these animals have been brought to light during the past century, and every one of them, so far as my own knowledge goes—and I have seen many hundreds—and so far as anything that has been published would indicate, is supposed to be of an adult or fairly mature animal. Not a single specimen which can be suspected to be embryonic is known. I hardly think that the same can be said of any other group of extinct aquatic animals. In the Cretaceous of Kansas the young of the plesiosaurs are fairly common, perhaps every third or fourth specimen showing immaturity. I have found

them in almost every stage of adolescence, and the embryos have been discovered in Europe. Furthermore, I have often sought in vain for the remains of young mosasaurs in the stomach contents of different animals in the Kansas Cretaceous, and in the bone-beds, which rarely occur in that formation. Under such apparently favorable circumstances as are presented by the chalk deposits of western Kansas, the seemingly entire absence of all remains of young mosasaurs is inexplicable. Half-grown forms do occur, but none that are very young. As I have previously remarked, it is certain that all mosasaurs did not die of old age. Indeed, the many hyperostosial mutilations of antemortem origin indicate only too well the fierce struggles the mosasaurs had with the carnivorous enemies of their own and other kinds.

If the mosasaurs were exclusively marine animals, it would seem almost certain that they were not viviparous, as were the ichthyosaurs, and probably also the plesiosaurs, and as are some modern lizards. As Fraas has remarked concerning the European ichthyosaurs, if one searches carefully, he will find in many Kansas specimens the remains of the skin and stomach contents, but never has there been found anything which has the faintest suggestion of mosasaur embryos. No aquatic reptiles of the present time lay their eggs in the water. The sea snakes are viviparous, or at least all available information concerning them gives viviparous habits. The sea turtles and the crocodiles lay their eggs upon the beaches, the latter guarding their nests and young. Doubtless the crocodiles of the past had the same beach-laying habits, suggesting that they were never inhabitants of the open oceans. The mosasaurs must have been practically helpless upon land; still it is not impossible that they may have frequented the beaches for the deposition of their eggs, though it is highly improbable that they gave any attention or care to either their eggs or their young. That the eggs of the mosasaurs were more numerous than are those of the terrestrial lizards of the present time is not to be supposed. The waters in which the mosasaurs flourished swarmed with highly predaceous fishes, sharks, and plesiosaurs, to say nothing of the hordes of their own kind; and,

unless the eggs were very numerous, or unless the young were jealously guarded by the parent, the young reptiles must have stood very little chance in the fierce struggle for existence.

It is, of course, possible that the shallow waters of the bays and estuaries may have afforded sufficient protection for the young mosasaurs, but this is doubtful, in the entire absence of all remains of such animals in marine deposits. It seems more probable that the mosasaurs were brought forth, perhaps alive, in fresh water, that the females ascended the rivers to breed, and that the young remained in such protected places until fairly able to care for themselves. That the mosasaurs, as also the aigialosaurs, were in part denizens of fresh water may be, perhaps, one reason for the great relative abundance of their remains in the deposits of inland or protected seas. Their occurrence in Kansas associated with great numbers of small turtles, pterodactyls, and birds would seem to be fairly good evidence that they were more littoral than pelagic in their habits.

That mosasaur remains have never been found in fresh-water deposits is not at all conclusive in controversion of this hypothesis. We know very little indeed, if anything at all, of the fresh-water life that existed during the times when the mosasaurs flourished. Possibly the Belly River deposits may furnish some evidence bearing on this hypothesis, though I suspect that the mosasaurs had disappeared in America before the time of those deposits.

It will be of interest to record here certain additional facts concerning the structure of the mosasaurs. A most extraordinarily complete specimen, referred to *Holosaurus abruptus* Marsh, discovered by Mr. E. B. Branson in western Kansas the past summer, has a slight emargination of the coracoids, finally and conclusively demonstrating the invalidity of this character in the separation of the genera. The scales of this form, as apparently also of other species of *Platecarpus*, are without carina.

The pubes meet in a perfect symphysis, not as they are always figured in text-books. The ilia were suspended vertically, and the depth of the body posteriorly is greater than the restorations indicate. The upper ends of the ilia were in relation, not

with the first of the pygal vertebræ, as I have contended, but with the second or third at least, as Dollo believed. There were more than ninety vertebræ in the tail. The skeleton measured more than twenty feet in length as it lay in the chalk, with nearly every bone in its proper position. The entire skeleton has been brought to the laboratory in chalk slabs, and when it is finally prepared will, I believe, add a number of new facts to our already full knowledge of these remarkable animals.

S. W. WILLISTON.

Reviews

SUMMARIES OF PRE-CAMBRIAN LITERATURE FOR 1902–1903. I.

[*Continued from Vol. X, p. 913.*]

C. K. LEITH.

ARTHUR KEITH. "Description of the Cranberry Quadrangle of North Carolina and Tennessee." *Geologic Atlas of the U. S.*, Cranberry Folio, No. 90, U. S. Geological Survey, 1903, pp. 1–9.

Keith describes and maps the geology of the Cranberry quadrangle of North Carolina and Tennessee, along the junction of the Piedmont Plateau and Blue Ridge. Archæan, and doubtful Algonkian, rocks occupy all but the northwest corner of the area. The Archæan rocks are mapped and described under the heads: Carolina gneiss, Roan gneiss, soapstone, Cranberry granite, Blowing rock granite, and Beech granite. The Carolina gneiss is the oldest rock of the ridge and consists of interbedded mica-schist mica-gneiss, and fine granitoid layers. The Roan gneiss consists of hornblende-gneiss, hornblende-schist, diorite, with some interbedded mica-schist and gneiss, all cutting the Carolina gneiss. Soapstone, resulting from the alteration of peridotite and pyroxenite, occurs in bodies closely associated with the Roan gneiss and probably of the same age. The Cranberry granite is the most extensive formation in the district, occurring chiefly in the mountain districts. It consists of granite and of schist derived from granite, and cuts the Roan gneiss and Carolina gneiss. All of the before-named rocks are cut by the Blowing rock gneiss and the Beech granite, which are considered to be of the same age.

Four formations are classed as doubtful Algonkian. These are: Linville meta-diabase — an altered greenish diabase and gabbro; Montezuma schist — a blue and green epidotic schist, probably altered basal, and amygdaloidal basalt; Flattop schist, — a gray and black schist, probably altered andesitic rocks; meta-rhyolite — a grayish meta-rhyolite and rhyolite porphyry. The first of these appears to be the lower part of a surface flow, and the last three are of surface volcanic nature.

T. L. WATSON. "Copper-bearing Rocks of Virgilina Copper District, Virginia and North Carolina." *Bulletin of the Geological Society of America*, Vol. XIII (1902), pp. 353–76.

Watson describes the copper-bearing rocks of the Virgilina copper district of Virginia and North Carolina and shows the adjacent rocks to be pre-Cambrian metamorphosed andesite associated with corresponding volcanic clastics. All are collectively referred to as greenstones, and are thought to be similar to greenstones described as occurring along the Atlantic coast region from eastern Canada to Georgia, and from Alabama to the Lake Superior region.

ARTHUR KEITH. "Geology of the Piedmont Plateau Area of the Washington Quadrangle." *Geologic Atlas of the U. S.*, Washington Folio, No. 70, U. S. Geological Survey, 1901, pp. 2, 3.

Keith describes and maps the geology of the Piedmont Plateau of the Washington quadrangles. Igneous rocks of Archæan age are mapped under the following headings; biotite-granite, soapstone and serpentine (altering from peridotite and pyroxenite), gabbro, meta-gabbro, diorite and meta-diorite (including granite, gneissoid granite and schistose granite), and Carolina gneiss (including mica-gneiss, mica-schist, and small bodies of granite, schistose granite, and diorite). In age these rocks rank in the order named, the Carolina gneiss being the oldest. Also the relative areas of the groups nearly correspond with their ages.

T. NELSON DALE. "Structural Details in the Green Mountain Region, and in Eastern New York." *Bulletin of the U. S. Geological Survey*, No. 195, 1902.

Dale sketches structural details in the Green Mountain district and in eastern New York, such as folds, cleavage, joints, and faults, some of them in the pre-Cambrian rocks.

F. J. H. MERRILL. "Metamorphic Crystalline Rocks of the New York Quadrangle. *Geologic Atlas of the U. S.*, New York City Folio, No. 83, U. S. Geological Survey, 1902, pp. 3–5.

Merrill describes the metamorphic crystallinc rocks of the New York quadrangle. Of these only one, the Fordham gneiss, is of pre-Cambrian age. The petrography of this gneiss is described. No opinion is expressed as to its sedimentary or igneous origin or as to its Algonkian or Archæan age.

C. H. SMYTH, JR., AND D. H. NEWLAND. "Report on Progress Made During 1898, in Mapping the Crystalline Rocks of the Western Adirondack Region." Eighteenth Annual Report of State Geologist for 1898 published in *Fifty-second Annual Report of the New York State Museum* (for 1898), Vol. II, 1900, pp. 129–35.

Smyth and Newland report progress in the mapping of the crystalline rocks of the western Adirondack region. Inclusions of hornblende schists found in the more acid gneisses of the region are believed to afford important evidence as to the origin of the gneisses. Also light red granitoid gneiss has been found intrusive into a gray gneiss, indicating, as before held, that all the gneisses are not of the same age. Certain of the gneisses are found to be younger than, and intrusive into, certain schists associated with the limestones.

H. P. CUSHING. "Recent Geologic Work in Franklin and S. Lawrence Counties, N. Y." Nineteenth Annual Report of State Geologist for 1900, published in *Fifty-third Annual Report of the New York State Museum*, Vol. I, 1902, pp. r23–95.

Cushing discusses recent geological work in Franklin and St. Lawrence counties, N. Y., and concludes:

1. That the Adirondack anorthosite is cut intrusively by an augite syenite, which is therefore younger.

2. That, while the larger part of the augite syenite of the Adirondacks is in such situation with respect to the anorthosite as to render impossible any determinations of relative age, its general character is so uniform throughout that it is exceedingly probable that it is all of the same approximate age and consists of intrusions from the same source.

3. That at their borders these syenites pass over into granites, part of which at least cut the syenite eruptively, and are therefore younger.

4. That the syenite grades into granite on the one hand, and into gabbro diorite on the other, and apparently into anorthosite as well.

5. That the three together, anorthosite, syenite, and granite, form a great eruptive complex in the heart of the Adirondack region, and that all are younger than the (in part at least) sedimentary Grenville rocks.

H. P. CUSHING. "Pre-Cambrian Outlier at Little Falls, Herkimer Co., N. Y." Nineteenth Annual Report of State Geologist for 1900, published in *Fifty-third Annual Report of New York State Museum*, 1900, pp. 183–95.

Cushing describes a pre-Cambrian outlier at Little Falls, in Herkimer county, N. Y., and points of difference with the syenite of the Adirondacks.

A. W. G. WILSON. "The Laurentian Peneplain." JOURNAL OF GEOLOGY, Vol. XI (1903), pp. 615–69.

Wilson describes the Laurentian peneplain of the great pre-Cambrian shield of Canada and adjacent portions of the United States. The peneplain is an ancient one, which has undergone differential elevation, has been denuded, and subsequently slightly incised around the uplifted margin. At several places on the margin, as exposed today, the dissection may be regarded as submature. The date of the major development of the peneplain is not determined, but may be pre-Ordovician or Cretaceous. Around the southern margin between Montreal and Winnipeg there are traces of a peneplain (or probably more than one) of still earlier date, upon which paleozoic sediments were laid down, and which has been uncovered by processes of degradation and denundation since the differential uplift of the latest peneplain.

S. WEIDMAN. "The Pre-Potsdam Peneplain of the Pre-Cambrian of North-Central Wisconsin." JOURNAL OF GEOLOGY, Vol. XI (1903), pp. 289–313.

Weidman describes a pre-Potsdam peneplain of the pre-Cambrian of north-central Wisconsin and shows the same to slope gradually to the south, where it is covered by Paleozoic sediments. Several monadnocks stand above the pre-Potsdam peneplain. Extensive clay deposits near the contact of the Paleozoic and the pre-Cambrian are believed to have developed during the pre-Potsdam base-leveling.

Comment.—The peneplain described by Weidman is perhaps to be correlated with the pre-Paleozoic peneplain described by Wilson as appearing about the periphery of the great pre-Cambrian area of Canada, with a slope inclined to the great peneplain of the pre-Cambrian interior. It is of interest also to note that evidence of pre-Cambrian base-leveling has been described by Crosby near Manitou, Col., and that Crosby has called attention to the widespread occurrence of such a plain in North America.[1]

[1] W. O. CROSBY, "Archæan Cambrian Contact Near Manitou, Col." *Bulletin Geological Society of America*, Vol. X (1899), pp. 141–64.

Reginald A. Daly. "Variolitic Pillow-Lava from Newfoundland." *American Geologist*, Vol. XXXII (1903), pp. 65–78.

Daly described variolitic pillow-lava from Newfoundland, and calls attention to the widespread occurrence of this or similar rocks, frequently called ellipsoidal greenstones, in Minnesota, New Brunswick, California, and Michigan.

R. W. Ells. "The Progress of Geological Investigation in Nova Scotia." *Proceedings and Transactions of the Nova Scotian Institute of Science*, Vol. X, Part 4 (1901–1902), pp. 433–46.

Ells summarizes the progress of geological investigation in Nova Scotia.

L. C. Graton. "On the Petrographical Relations of the Laurentian Limestones and the Granite in the Township of Glamorgan, Haliburton County, Ontario." *Canadian Record of Science*, Vol. IX (1903), pp. 1–38.

Graton describes in detail the petrographical relations of the Grenville limestones and granite in the township of Glamorgan, Haliburton county, Ontario. His conclusions are of importance as bearing on the relations of limestones and gneisses over other extensive areas in eastern Canada, the Adirondacks, and New Jersey. He summarizes his conclusions as follows:

The district exhibits a development of Grenville limestone pierced by intrusions of gneissic granite which contain masses of dioritic rock.

Considerable deformation took place during the intrusion.

Between the limestone and the granite is a highly brecciated zone, holding large amounts of lime-rich silicates which are eminently characteristic of contact metamorphism.

Diagenesis took place.

To a great extent, however, the elements, other than the lime necessary for the formation of these minerals, came from the intrusion and its accompanying exhalations.

The metamorphism, then, was largely also metasomatic.

In the gray gneisses and in the granite are dark basic masses which represent fragments broken off from the limestone series and floated away into the igneous mass. They have been still more highly metamorphosed than the rocks from which they came, and have been more or less dissolved and changed in character by the granite. In other words, they have been partially "granitized."

The gray gneisses, which have the composition of quartz diorites, may represent an intermediate phase of this "granitization"—between the inclusions and the granite. This theory may account for the large amount of plagioclase feldspar found in the granite itself.

R. W. Ells. "Report on the Geology of Argenteuil, Ottawa and Part of Pontiac Counties, Province of Quebec, and Portions of Carleton, Russell and Prescott Counties, Province of Ontario." *Annual Report of Geological Survey of Canada*, Vol. XII (1899), New Series, pp. 1j–138j.

Ells maps and describes the geology of Argenteuil, Ottawa, and part of Pontiac counties, province of Quebec, and portions of Carleton, Russell, and Prescott counties, province of Ontario, covering most of what has long been known as the Original Laurentian district, and summarizes previous work in this district. Archæan rocks,

occupying most of the area north of the Ottawa River, are mapped as crystalline limestone, gneiss, quartzite, anorthosite, granite-gneiss and porphyry. In the text the limestones with the quartzites and gneisses associated with them are described as sedimentary and are classed as Grenville, and the underlying gneisses and granite-gneisses are described as of igneous origin and are called Fundamental complex—in this classification following previous writers. It is evident that the rocks of the Grenville series are decidedly newer than those of the Fundamental division. As for the numerous and often large area of red granite-gneiss, many of these are undoubtedly of more recent date than either of the others since they clearly cut both the gneiss and limestone. While in some points the newer granite-gneiss presents features similar to the Fundamental division, as in the foliation of certain portions, there is, over large areas, a marked difference in their aspect in the field.

A. OSANN. "Notes on Certain Archæan Rocks of the Ottawa Valley." *Annual Report of the Geological Survey of Canada,* Vol. XII (1899), New Series, pp. 10–840.

Osann makes a detailed petrographic description of the crystalline rocks in the Original Laurentian area of the Ottawa Valley.

WILLET G. MILLER. "Lake Temiscaming to the Height of Land." *Report of the Bureau of Mines,* Ontario, 1902, pp. 214–30.

Miller publishes geological notes taken on a canoe trip from Lake Temiscaming northward to the height of land. Special attention was paid to occurrence of minerals of commercial value, and no mapping was attempted. He finds various kinds of igneous rocks, both plutonic and volcanic, such as granite, syenite, diorite, olivine diabase, quartz-porphyry, and others of less importance. In addition to these, most of the metamorphic fragmental rocks characteristic of the Huronian occur, among which may be mentioned quartzite, slate graywacke, and different varieties of the pyroclastic series, ash rocks, and agglomerates. The popular belief that the height of land in this district represents the highest point of the surface from which sediment was derived for the formation of deposits of later age which lie to the southward is scarcely based on fact. He found what appear to be thick deposits of Huronian conglomerate and other water-formed material resting on the surface close to the height of land. It is evident from this that the surface level must have changed considerably since Huronian times, and that what is now the height of land may have once been a comparatively low-lying area.

L. L. BOLTON. "Round Lake to Abitibi River." *Report of the Bureau of Mines,* Ontario, 1903, pp. 173–90.

Bolton reports on the geological reconnaissance from Round Lake north to the Abitibi River in the district of Nipissing. Laurentian granite was seen near both the southeastern and southwestern corners of Eby. Elsewhere Huronian rocks are exposed. Of these there is a considerable variety, many of which are of fragmental origin. The following types were seen: diorite, diabase, brecciated conglomerate, slate, graywacke, hornblende schist, etc. As the rock outcrops of the district explored are, as a rule, separated by areas of sand, swampy, or clayey soil, the relations of the different types could seldom be worked out.

A. P. COLEMAN. "The Sudbury Nickel Deposits." *Report of the Bureau of Mines*, Ontario, 1903, pp. 235–303.

Coleman describes and maps the nickel deposits near Sudbury, Ontario, and incidentally discusses the geology of the region. The probable succession and age of the rocks of the district is as follows, in ascending order:

Keweenawan (?) { Dikes of diabase.
Younger Granite.
Nickel-bearing eruptive; norite; micropegmatite; granite. }

Animikie (?) or Upper Huronian (?) — Oval area of tuffs, sandstones, and slates overlying the preceding.

Laurentian.—Granitoid gneiss.

Upper Huronian { Green schists and greenstones.
Arkoses, quartzites, and graywackes. }

It can hardly be said that the precise age of any of these groups of rocks is known, though they probably range from the base of the Upper Huronian to the Keweenawan, including the Laurentian as later than the Upper Huronian. No rocks undoubtedly of Lower Huronian age are known from the nickel district proper; though the ranges of banded silica and magnetite extending through Hutton and Wisner townships to the north of the nickel area evidently belong to the Lower Huronian.[1] The latter rocks occur entirely inclosed, so far as known, in granites and gneisses, generally considered Laurentian, and have not been found in direct connection with the rocks here described.

The fact has been brought out that all of the nickel deposits are either on the basic edge of a great eruptive band, which at the opposite edge becomes a quartz syenite or granite, or in dike-like offshoots, often, however, interrupted by other rocks projecting from the southeastern basic edge of the great gabbro band. This band has been found to outcrop in a great oval, the north and south sides of which have been known respectively as the North and South nickel ranges. The structure is synclinal, and the center is occupied by Animikie or Upper Huronian rocks.

There are two different types of deposits represented in the mines of the district: those along the southeastern margin of the main range, often crowded into bay-like indentations of the adjoining rock; and those strung out along the narrow off-shoots from the main range, as Peters suggests, "like sausages on a string, but with a long piece of string between the sausages."[2] Among the former class are the Creighton, Gertrude, Elsie, Murray, and Blezard mines; among the latter, the Copper Cliff, Evans, Frood and Stobie, and the Victoria and Worthington mines. Perhaps a third variety should be distinguished for the Vermilion mine, which contains rich nickel and copper ores, but has no visible association with a band of gabbro, having, however, been formed probably by hot circulating fluids proceeding from such a band.

The final impression left is that the marginal type of deposit is in the main of plutonic origin, aqueous work being relatively unimportant; that in the offset type plutonic is generally more important than aqueous action, though one example, that of the Worthington, suggests more complete rearrangement of the materials by circulating water; thus forming a transition to ordinary vein deposits wholly due to water action, as at the Vermilion mine.

[1] *Report of the Bureau of Mines*, 1901, p. 186.

[2] *Mineral Resources of Ontario*, p. 104.

C. K. LEITH. "Moose Mountain Iron Range." *Report of the Bureau of Mines*, 1903, pp. 318–21.

Leith describes the Moose Mountain iron range in the township of Hutton and district of Nipissing. Iron formation consisting of magnetite, of banded magnetite and quartz, and of magnetite, associated with amphibole and epidote, occurs in bands and lenses in a complex of basic igneous rocks characterized by uniform abundance of amphiboles. Some of the greenstones are basal and some intrusive into the iron-bearing bands. Intrusive into the greenstone and probably into the iron formation are granite masses. Closely associated with the iron formation, but with relations unknown, is a pyritiferous graywacke. The ores and associated rock as a whole are in general similar lithologically to the Vermilion iron-bearing district of Minnesota, although showing many points of difference.

Comment.—Further field work in 1903 in adjacent areas indicates that a great graywacke and conglomerate series rests unconformably against the rocks of the iron range, thus adding another point of similarity of this range to the Vermilion iron range of Minnesota.

L. C. GRATON. "Up and Down the Mississaga." *Report of the Bureau of Mines*, Ontario, 1903, pp. 157–72.

Graton reports on a geological reconnaissance along the Mississaga River and east and west along Niven's baseline in the district of Algoma. Laurentian granites occupy all of the area north of township 188, where was found a greenish slate conglomerate belonging to the Huronian.

W. G. MILLER. "Iron Ranges of Northern Ontario." *Report of the Bureau of Mines*, Ontario, 1903, pp. 304–17.

Miller gives a résumé of the occurrence of iron ore in northern Ontario, and incidentally discusses their geological relations.

A. P. COLEMAN. "Iron Ranges of Northwestern Ontario." *Report of the Bureau of Mines*, Ontario, 1902, pp. 128–51.

Coleman gives results of an examination of the iron ranges of northwestern Ontario, principally the Mattawan, Atikokan, Steep Rock Lake, and other districts along the Canadian Northern Railway, the Slate Islands in Lake Superior, and near Dryden on the Canadian Pacific. The description of the details of the districts contains but few references to general stratigraphy and correlation, but at the end a general classification of the iron ores of Canada is given. To the upper part of the Lower Huronian (Archæan of the U. S. Geological Survey) are referred the siliceous and sideritic iron ranges occurring in practically every iron-bearing area in Ontario, but being mined at only one place, at the Helen mine in the Michipicoten district. To the lower part of the Lower Huronian are referred the magnetite lenses in green schists of the Atikokan district and the titaniferous magnetite, occurring as segregations in basic eruptives, especially gabbro. To the Grenville series "probably Huronian" are referred the magnetite and hematite ores associated with bands of crystalline limestone and gneiss of eastern Ontario. To the Animikie or Lower Huronian (Upper Huronian of the U. S. Geological Survey) are referred impure siderite and hematite occurring in the neighborhood of Thunder Bay and also near Algoma. To the Pleistocene are referred the bog and lake ores and postglacial magnetic sands occurring widely in Ontario and especially in the eastern part.

A. P. COLEMAN. "Nepheline and Other Syenites Near Port Coldwell," Ontario. *American Journal of Science*, Vol. CLXIV (1902), pp. 147–55. See also *Report of Ontario Bureau of Mines* for (1902), pp. 208–13.

Coleman describes nepheline and other syenites near Port Coldwell, Ontario, and calls attention to their widespread distribution in Ontario and the United States.

W. G. MILLER. "Nepheline Syenite in Western Ontario," *American Geologist*, Vol. XXXII (1903), pp. 182–85.

Miller describes bowlders of nepheline syenite near Sturgeon Lake, northwest of Lake Superior, indicating the occurrence of rocks of this character in the pre-Cambrian rocks farther north.

R. G. MCCONNELL. "Note on the So-called Basal Granite of the Yukon Valley." *American Geologist*, Vol. XXX (1902), pp. 55–62.

McConnell describes the granite gneiss of the upper part of the Yukon Valley, extending from the Nordenskiold River in a northwesterly direction across the White River valley to the Tanana, and down this stream to near the mouth of the Delta River — a total distance of about 380 miles — and concludes that a part of the gneisses at least must be regarded as intrusive through, and therefore younger than, the clastic schists associated with them. It is still possible, however, as the work done so far has been largely of an exploratory character, that older gneisses may be present in the district, but no evidence of this was obtained in the course of the investigation.

O. H. HERSHEY. "Structure of the Southern Portion of the Klamath Mountains, California." *American Geologist*, Vol. XXXII (1903), pp. 231–45.

Hershey discusses the structure of the southern portion of the Klamath Mountains, of California. The oldest rocks in the mountains west of the Sacramento River are the Abrams mica-schists, 1,000 feet thick, and overlying it the Salmon hornblende-schist, known to be at least 2,500 feet thick, both of them supposed to be of pre-Cambrian age, probably Algonkian, and possibly Archæan. The Abrams mica-schist is a sedimentary rock, and the Salmon hornblende-schist is a metamorphosed volcanic ash. The Klamath schists form the central ridge of the Klamath region. They are bordered on the west by a great, unsymmetrical geosyncline, and on the east by the western limb of another great geosyncline. The first geosyncline is limited on the west by another belt of schist, chiefly the Abrams mica-schist, which forms the South Fork Mountain and is prolonged northwestward to and probably across the Klamath River near Wichiper. The sandstones of the Coast Range region adjoin this schist belt on the west. According to Mr. Diller, toward the north, approaching the Klamath River, long narrow belts of schist alternate with narrow belts of sandstone, the latter dipping eastward as though going under the schists. This apparent anomaly is evidently due to a series of faults. It is further evident that the Coast Range formations have buried the western portion of the schist belt which may extend, immediately under the sandstone, far toward the coast.

The eastern schist belt emerges from beneath the Cretaceous sandstones and shales in the Sacramento valley west of Ono, with a width of eight miles and

gradually increases as it advances northward to a maximum of about twelve miles west of Scott Valley. Southward from the Trinity River, the pre-Paleozoic area is occupied chiefly by the Abrams mica-schist, the hornblende-schist being confined to narrow strips, but northward from the Trinity River the hornblende-schist spreads out and finally nearly excludes the mica-schist as in the valley of the South Fork of the Salmon River. Still farther north, in the mountains west of Scott Valley, the mica-schist has again asserted its supremacy.

O. H. HERSHEY. "Some Crystalline Rocks of Southern California." *American Geologist*, Vol. XXIX (1902), pp. 273–90.

Hershey describes the results of a brief examination of the Fraser Mountain and Sierra Pelona regions, and portions of the Tehachapai, Sierra Madre, and San Bernardino ranges, together with quite an extended section of Mohave desert, all comprised in the counties of Los Angeles, Ventura, Kern, and San Bernardino of California. The crystalline rocks are discriminated under the following heads: (1) "The Pelona Schist Series;" (2) "The Gneiss Series;" (3) "The Rocks of Fraser Mountain and Vicinity;" (4) "The Mesozoic Granites;" (5) "The Ravenna Plutonic Series;" (6) "The Gneiss Near Barstow;" (7) "The Quartzite-Limestone Series of Oro Grande;" (8) "The Schists in Cajon Pass."

The Pelona schist series and the adjacent gneisses, the rocks of Fraser Mountain and vicinity, and the gneiss near Barstow are tentatively correlated with the Abrams schist of the Klamath region in a general way, and are considered pre-Paleozoic, perhaps in part Archæan and in part Algonkian.

W. LINDGREN. "The Gold Belt of the Blue Mountains of Oregon." *Twenty-second Annual Report of the U. S. Geological Survey*, Part II, 1900–1901, pp. 551–776.

Lindgren describes and maps the geology of the gold belt of the Blue Mountains of Oregon. Gneiss, referred to the Archæan, occurs northwest of Blue Mountain above La Belleview mine.

BAILEY WILLIS. "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana." *Bulletin of the Geological Society of America*, Vol. XIII (1902), pp. 305–52.

Willis describes and maps the stratigraphy and structure ot the Lewis and Livingston Ranges of the Front Range of the Northern Rocky Mountains of Montana and Alberta. Lewis and Livingston Ranges consist of stratified rocks of Algonkian age, as determined on fossils which were found by Weller in the lowest limestone of the series, and identified by Walcott as probably being Beltina danai, the species of crustacean discovered in the Grayson shales of the Belt Mountains. The Algonkian series consists of limestone, argillite, and quartzite, classified in five formations, and aggregating about 12,500 feet in thickness. The formations are the Kintla argillite, Sheppard quartzite, Siyeh limestone, Grinnell argillite, and Appekunny argillite. There is apparent conformity throughout. The series is so situated with reference to other rocks that no lower or upper stratigraphic limit could be determined. Dr. G. M. Dawson classified with strata as Cambrian, Carboniferous, and Triassic, but it is believed that he mistook certain local overthrust faults for unconformities, and was misled by lithologic resemblances.

Igneous rocks occur sparingly in the Algonkian series. An intrusive sheet of diorite is extensive in the upper limestone formation and an extrusive flow of diabase caps it.

The Algonkian strata form a syncline whose axis trends west of north. Southwestern dips vary from 5° to 30°. Northeastern dips are generally 30° to 40°, and locally approach or pass verticality. Minor flexures within the syncline are very broad and low. The northeastern limit of the fold is an eroded margin; the southwestern is an anticlinal axis whose western limb is in part eroded, in part thrown down by a normal fault along North Fork Valley. Syncline and anticlines are closely related to valley and ridge respectively, and this relation extends to heights of peaks.

Along its eastern margin the oldest Algonkian formation rests upon Cretaceous rocks. The outcrop of this abnormal contact is deeply sinuous throughout the stretch from Saint Mary Lake to Waterton Lake. The structure is described as an overthrust fault, on which the Algonkian series has moved northeastward relatively over the Cretaceous rocks. The displacement on the thrust surface is 7 miles or more, and the vertical throw is estimated at 3,400 feet or more. The thrust surface dips from 0° to 10° southwestward, and strikes variously from north to north 60° west. Thus it is warped, and this warping is found to determine the general outline of the eastern face of the Rocky Mountains, particularly the prominence of Chief Mountain, and the relative position of the Lewis Range, en echelon to the Livingston.

W. H. WEED. "Geology and Ore Deposits of the Elkhorn Mining District, Jefferson County, Montana." *Twenty-second Annual Report of the U. S. Geological Survey*, Part II, 1900–1901, pp. 399–549.

Weed describes and maps the geology of the Elkhorn mining district of Montana. Doubtfully referred to the Algonkian are the Turnley hornstones. The lower division is 200 feet thick and consists of shale metamorphosed to a very dense hornstone composed of light brown biotite and quartz. A bed of impure iron ore 20 to 30 feet thick occurs in the middle lower part of the formation. The quartzitic hornstones overlie the basal beds just noted and are 200 feet thick. The rocks, though well bedded, are very dense and hard, and are of a gray-black color, so that they closely resemble the andesites. In color, composition, and relation to the overlying quartzite the rocks correspond to the red Spokane shale of the Belt terrane seen at Whitehall, 20 miles south, at Townsend to the east, and at Helena on the north.

W. S. TANGIER SMITH. "Geology of the Hartville Quadrangle of Wyoming." *Geologic Atlas of the U. S.*, Hartville Folio, No. 91, U. S. Geological Survey, 1903, pp. 1–6.

Smith (W. S. Tangier) describes the geology of the Hartville quadrangle of Wyoming. The Whalen group, assigned to the Algonkian, consists of gneisses, schists, quartzites, and limestones, all very schistose, the schistosity standing nearly vertical. These rocks occur principally in the northeastern part of the quadrangle. Quartzites and micaceous schists form the greater part of the exposed rocks of the Whalen group, and in places they grade into each other, so that no definite separation can be made. Some of the quartzites are more or less calcareous. Iron ore occurs within and near the contact of the limestones and schists of the Whalen group on the west side of Whalen Canyon. Information at hand is not sufficient to decide whether there are several ore-bearing horizons or a single horizon repeated by folding. Ore is being mined at Sunrise.

F. L. RANSOME. "Ore Deposits of the Rico Mountains, Colorado. *Twenty-second Annual Report of the U. S. Geological Survey,* Part II, 1900–1901, pp. 229–397.

Ransome describes the ore deposits of the Rico Mountains, Colorado, and incidentally summarizes the geology of the area, referring the reader to a previous paper by Cross and Spencer[1] for further details. The Algonkian rocks consist of quartzites and schists, exposed just north of Rico and in the canyon of Silver Creek. They appear as fault blocks, in the heart of the dome, thrust up from below into the later beds.

WHITMAN CROSS. "Geology of the Silverton Quadrangle, Colorado." From *Bulletin No. 182, U. S. Geological Survey,* 1901, by F. L. RANSOME.

Cross summarizes the geology of the Silverton quadrangle, Colorado, for Ransome's bulletin on the economic geology of this quadrangle. Algonkian quartzites and schists appear beneath the volcanics where the Animas River and the Uncompahgre River and its tributaries cut through the volcanics.

Irrigation. By F. H. NEWELL. New York: T. Y. Crowell & Co.

MR. NEWELL'S book is written from the economic and social point of view, and emphasizes the importance of irrigation as a national problem. For this reason the general reader, as well as the person directly concerned in home-making in the arid West, will read the work with interest. Guided by his extensive experience with problems of irrigation, the author contrasts the present scanty occupation of the western two-fifths of the United States with the possibilities for home-making when the present water supply shall have been properly conserved.

At the present time 7,300,000 acres are under irrigation, while the natural water supply is sufficient for ten times that acreage. The success already attained in this small fraction of the area abundantly justifies the national expense already incurred, and becomes the basis for urging national aid in bringing greater areas under irrigation. Certainly the addition of 60,000,000 acres, equivalent to two states the size of Pennsylvania, to the present productive area of the public domain is an expansion in the right direction. The fact that these lands capable of irrigation are distributed, oasis like, through regions which must always yield but scanty returns, and that these areas have a calculable productivity equal to the best land in humid states, are

[1] WHITMAN CROSS AND A. C. SPENCER, "Geology of the Rico Mountains, Colorado," *Twenty-first Annual Report of the U. S. Geological Survey,* Part II, 1899–1900, pp. 1–165; summarized in JOURNAL OF GEOLOGY, Vol. X (1902), p. 910.

convincing arguments for national control, and for protection from speculative monopoly.

The author lays much stress upon the fact that problems arise from irrigation that cannot be successfully handled by individuals or even by states. The setting apart of forest lands for the regulation of the water supply; the building of reservoirs for impounding the head-waters of streams; the adjusting of water rights on streams that cross state lines; the establishing of experiment stations; and the investigation of a wide range of conditions of water supply and the adaptation of crops to climate and soil—these are subjects for an authority which can act in a disinterested way for all concerned.

As the book is intended for popular reading, it is in no sense a manual, though the practical man will find that fundamental principles have been so clearly stated, and happily illustrated by photographs and diagrams, that he can judge intelligently concerning his own particular conditions, and avoid expenditure on ill-advised schemes. The manner in which the author deals with the questions of artesian water, the building of dams and ditches, the use of windmills as a source of power, the methods of measuring water, and the means of conducting water to land in a great variety of situations, must appeal to the common-sense of every practical farmer.

Sixty-two plates and ninety-four diagrams admirably supplement the lucid text. Among the cartograms are a number that show in a striking way the relative size of western states as compared with the Atlantic states, and are well calculated to impress the reader with the vastness of the area with which the book deals. If the book were supplied with definite references to the wide literature of the field, it would be of more use to students; but as it is, it furnishes an excellent introduction to the subject.

L. H. Wood.

Gems and Gem Minerals. By Oliver Cummings Farrington, Ph.D., Curator of Geology, Field Columbian Museum. Pp. 229+xii. Chicago: A. W. Mumford, 1903.

In this book it has manifestly been the intention of the author to make the treatment of the subject as non-technical as possible. At the same time, scientific terms have been used whenever these were necessary to give the matter accuracy and definiteness. The subject as a whole has been discussed from the mineralogical standpoint, each gem being considered under the mineral species to which it belongs. Fol-

lowing this idea, ruby and sapphire are treated under corundum; emerald and aquamarine, under beryl, etc.

At the outset a brief discussion of the nature of gems is given, and the characteristics or qualities for which they are prized are enumerated. Following a few pages devoted to the geographical and geological occurrences of gems, the more common methods of gem-mining are described. Since the coloring of gems is one of the most essential features of their value, the significance and meaning of the color elements are considered, and a list of gems is given arranged according to colors. The subjects of luster and hardness come next, followed by a table showing the hardness of gem minerals. Methods for the determination of specific gravity are described, since herein is a reliable means of distinguishing between gems of different kinds, and of separating false from real stones. Next comes in turn, a discussion of the optical properties, electrical properties, phosphorescence, and fluorescence of gems. The crystal form of gems is then considered to some extent, since this characteristic often affords a ready method for their identification. Methods of cutting and mounting gems are given in some detail, and a number of line engravings have been prepared showing the usual forms of cutting. Next come chapters on the valuation and price of gems, imitation gems, and how to detect them, superstitions regarding gems, and birth-stones.

Following the general matter noted above, the individual gem minerals are considered, the first being the diamond. In the discussion of the diamond its characteristics are pointed out, and the diamond fields and the famous diamonds that have been discovered are described, along with much other matter of general interest. In a similar fashion, the several gems afforded by the mineral species corundum are discussed; and then come in turn spinel, beryl, chrysoberyl, tourmaline, topaz, garnet, opal, and all other minerals, as well as some substances of animal and vegetable origin which have been used to any degree for purposes of adornment.

The book is neatly printed and bound, and contains a large number of half-tones and line engravings, as well as sixteen full-page illustrations in color of rare excellence. In bringing together in compact form so very much interesting matter concerning our gem minerals, Dr. Farrington has performed a service that will be greatly appreciated both by the mineralogist and the general reader.

H. L.

Editorial.

That the rapid growth of special scientific nomenclatures is a serious burden is felt by every scientific worker. Any effort, accordingly, toward harmonizing conflicting usage should be and is welcome. Not every such effort necessarily produces final results, but if systematically pursued, it can hardly fail to eliminate some confusion. In the work of the United States Geological Survey decisions are constantly required of questions relating to the naming and correlating of geologic formations. In many instances the available evidence is so conflicting or so meager as to preclude final judgment. Nevertheless, if geologic work is to go on, and maps are to be made, a definite usage must in each case be authorized. These decisions establish precedents, which from time to time receive formal statement by the director and become rules. Such a code, if we may borrow the legal term, was published in the *Tenth Annual Report* of the Survey, and in the *Twenty-fourth Report* is republished, revised, and enlarged by the incorporation of the precedents established in the last thirteen years, together with certain other changes recommended by the committee charged with the revision.

In the new rules there are many minor and some major changes from the old. The action of the committee has been conservative in some directions and radical in others. In part the changes are seemingly retrogressive, though it is to be remembered that a wise progression never hesitates to abandon a position which experience has proved untenable. The return to the use of "Tertiary," "Quaternary," "Triassic," and the adoption of "Ordovician" as a systematic term, with the recognition of the quadruple Lyellian divisions of the first-named are movements which will bring the publications of the survey into closer harmony with those of other organizations, and are fully warranted by the developments of the last decade. The extension of the criteria for the recognition of formations so as to include

physiographic data, and to allow fossils to be used for discrimination as well as for correlation, will, it is believed, be generally approved. To meet the practical difficulties of mapping, lithologic units smaller than formations may, when sufficiently important, be separately mapped as members or lenses. An effort is to be made to conform in the general plan of mapping to the logical categories of (*a*) sedimentary, (*b*) igneous, (*c*) metamorphic rocks. Surficial rocks of all ages are treated as a subclass of sedimentaries, but are to be distinguished by patterns in mapping on a genetic basis. The stratified rocks of the Archean and Quaternary are given distinctive colors. There are many other changes apparent when the old and new rules are compared.

Rules of nomenclature will not, unfortunately, be consistently applied if the interpretation be left entirely to each individual worker. To meet the necessities of the present case a Committee on Geologic Names has been constituted, to consider and decide the various difficulties which will inevitably arise in the varied work of the Geological Survey. This committee is charged with the inspection of all papers written by any member of the Survey corps, and as part of its work keeps a complete card catalogue of all formation names proposed or used in writings relating to American geology.

The closer co-operation of the various individuals and organizations concerned in the advancement of geologic science in this country is surely desirable, and much misunderstanding and unproductive effort can certainly be eliminated if common usage of geologic formation names can be brought about. While a committee from the Survey, representing as it does only a part, even though the larger part, of American geologists, can in the nature of the case, have no authority over the publications of geologists not belonging to its own corps, yet it is hoped that general appreciation among geologists of the advantages of so doing will induce individual and independent workers to avail themselves of its functions, and to conform, when possible, to the usages of the large body of their geological colleagues governed by its decisions.

H. F. B.

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THE

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FEBRUARY–MARCH, 1904

ARTESIAN WELL SECTIONS AT ITHACA, N, Y.[1]

THE WELLS.[2]

DURING the typhoid epidemic at Ithaca, N. Y., in 1903, a committee of citizens began explorations for a source of artesian water to replace the surface supply then in use. This work was continued by the Ithaca water board, and the result was the sinking of thirteen wells in a limited area on the southern outskirts of the city. Prior to this an artesian well had been developed in the same area, yielding a daily flow of about 300,000 gallons from a series of Pleistocene gravels at a depth of about 280 feet. A majority of the new wells found water in what appear to be the same gravels; others failed to develop water.

Besides these deep wells, there are a large number of shallower ones in the city of Ithaca which obtain artesian water in a gravel series found at depths usually from 50 to 100 feet.

[1]Published by permission of the Director of the United States Geological Survey.

I am indebted for valuable assistance in the preparation of this paper to the following gentlemen: Mr. C. C. Vermeule, engineer in charge of the boring of the wells, for directing that samples be preserved for me; Mr. F. L. Getman, his assistant, for collecting the samples and for other valuable information; Mr. Lawrence Martin, of Cornell University, for aid in gathering information, and in consideration of the nature of the well sections; Dr. G. K. Gilbert, for placing at my disposal certain facts from his notebooks bearing upon the question of tilting of the land in central New York; Dr. William H. Dall, for identifying the mollusca; and Professor D. P. Penhallow, for identifying the plant remains.

[2]A more detailed statement of the bearing of this exploration on local water supply will be published by the U. S. Geological Survey.

IMPORTANCE OF THESE WELLS.

These wells have yielded three important geological results: (1) They have in two cases revealed the exact depth of filling by Pleistocene deposits, and have therefore given some additional facts concerning the form and depth of the Cayuga Valley. (2) Since samples were collected at frequent intervals in several of the wells, and records kept of all, they have revealed the structure underlying the Ithaca delta down to the rock floor. (3) They have thrown some light on the occurrence of artesian water in Pleistocene deposits.

DEPTH OF DEPOSITS.

The wells are all located near the western margin of the delta on which the main portion of the city of Ithaca is built. The surface soil is clay and muck, and the region is evidently one reclaimed from Lake Cayuga by the same processes of lake filling that are now at work on the outer edge of the delta on the north side of the city. While low and swampy throughout much of its area, this nearly level delta rises perceptibly toward the creeks that descend through gorges cut in the valley walls. These elevated sections are low, flat alluvial fans, raised above the general delta level by deposits brought down by the torrential streams that occupy the hillside gorges.

The delta also rises gently toward the south, and at a distance of about two miles south of Ithaca abruptly ends against the north face of the morainic complex which fills the valley thence to its present divide. It is evident that this moraine descends beneath the delta deposits.

Two of the borings reached bed-rock, one (Fig. 1, *C*) at a depth of 260 feet, the other (Fig. 1, *G*) still further out in the valley, at a depth of 342 feet. A profile of the valley at this point is shown in Fig. 2. Farther north (Fig. 1, *A* and *B*) two wells, bored to the underlying salt, encountered rock at 430 and 401 feet respectively, the latter being 1,500 feet south of the former.

These borings are not numerous enough to warrant any conclusions further than that the maximum depth of the valley is at

least 430 feet below the delta at Ithaca, or about 25 feet below sea-level. Since soundings in Lake Cayuga reveal a depth of 435 feet in the deepest point, in which, of course, there is at least some filling, the borings at Ithaca do not add to the known depth of the valley. It is not to be inferred, however, that the deepest boring at Ithaca, although near the middle of the valley, really represents the deepest part of the valley in this region.[1] The discovery of rock in these wells shows that the general slope of the lower valley walls is continued down with practically no change (Fig. 2), at least to the depth reached in the artesian wells (Fig. 1, *C* and *G*).

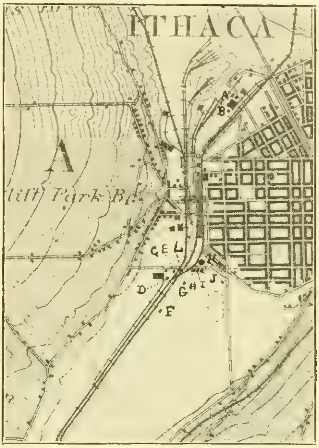


FIG. 1.—Section of the "Ithaca Sheet" (U. S. Geological Survey) to show the location of the artesian wells. *A*, *B*, salt wells, rock at 430 and 401 feet respectively; *C*, Strang Well, No. 1, 286 feet, struck rock at 260 feet; *D*, Millard Well, No. 2, 259 feet; *E*, Old Clinton St. Well, 280 feet; *F*, South Well, 232 feet; *G*, Strang Well, No. 2, 352 feet, struck rock at 342 feet; *H*, Trapp Well, 332 feet; *I*, Holmes Well, 291 feet; *J*, Millard Well, No. 1, 303 feet; *K*, several wells, close together, as follows: Illston Well, 286 feet; Strang Well, No. 3, 280 feet; Strang Well, No. 4, 279.9 feet; Strang Well, No. 5, 276 feet; and Strang Well, No. 6, 295 feet; *L*, Millard Well, No. 3, 303 feet.

DESCRIPTION OF THE WELL SECTIONS.

Both in the deeper artesian wells and in shallow ones in the city of Ithaca the upper layers are found to be a fine-grained, massive clay. In two cases it is reported as sandy. This clay layer is absent, or at least not continuous, near the eastern wall of the valley where alluvial fans have been built opposite the stream mouths. The depth of the clay stratum varies from approximately 40 to 60 feet. Fragments of mollusca and plant fragments, including pieces of reeds and wood, were found in several of the samples from this clay layer; and in two cases logs were encountered, one at 38–39 feet, another at 33 feet.

[1] It is noteworthy, in this connection, that a well near the center of the Seneca Valley at Watkins had not reached the bottom of the drift deposits at a depth of 1,080 feet.

Beneath this clay layer, in every well of which there is a record, a series of coarser beds is found. These coarse beds vary greatly even in neighboring wells; but in most cases there are both sand and gravel layers. The bottom of the series of coarse sediments varies from 60 to approximately 120 feet, and the thickness in individual wells from 20 to about 70 feet. The coarser sands are clear and well washed; the gravels consist of well-rounded pebbles similar to those now brought down by the torrential creeks that enter the valley.

In most of the samples preserved from these coarse layers plant fragments and mollusca were found. Seven logs were encountered, and the two logs found in the overlying clays were almost down to the level of the coarser series. Thus between the depth of 35 and 119 feet nine logs were encountered in boring thirteen six-inch wells. Since two of the wells passed through two logs each, logs were encountered in seven out of thirteen wells. The depth of the several logs is given in the following table:

Wells	Depth in Feet	Material
Strang	56 –58	Gravel
Old Clinton St	63	Sand
Millard 3	38 –39	Clay
Millard 3	118 –119	Sand
Trapp	48½–50½	Gravel and sand
Trapp	55½–56½	Gravel and sand
Millard 1	50 –51½	Sand and pure gravel
South	33	Clay, somewhat sandy
Strang 3	110 –112	Probably at bottom of gravel

In all the deep wells the coarser layers are underlain by a great thickness of clay, in which no molluscan remains were found, though in several samples small, indefinite plant fragments occur. In most of the wells the driller failed to preserve more than one sample, which he considered typical of the entire clay mass; but near the top and bottom of the series the material is occasionally reported as "clay and stone," "clay and gravel," or "clay and sand." In one well (the south well), however, samples were preserved every ten feet, and these samples show clearly the nature of the material. From top to bottom, that

is, from 70 to 200 feet, it is a fine-grained clay, at all depths lower than 100 feet containing small angular pebbles, in some cases scratched. These stones increase in number and size toward the bottom, and the proportion of sand increases to such an extent that below the depth of 135 feet the well-driller calls it a sandy clay. But down to the 200-foot level the stratum is unquestionably clay.

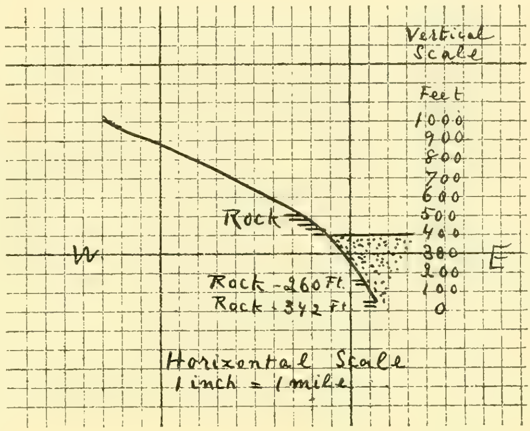


FIG. 2.— Profile of the hill slope on the western side of the Cayuga Valley at Ithaca just west of the artesian well sites. This profile is continued down to the points where rock was reached in the artesian wells. (Horizontal scale, 1 mile to the inch; vertical scale, 1,000 feet to the inch.)

Owing to the indefiniteness of the nomenclature used by well-drillers, and the failure in many cases, to preserve samples it is not always easy to state exactly where the bottom of the clay series is. Using the best judgment possible, I place the base of the clay series in the thirteen wells as follows: 220, 210–30, 262–76, 238–78, 230, 225–76, 200, 214–80, 202–22, 244–70, 240, 242–46, 234–70. The well which gives the 200-foot level for the bottom of the clay is the one from which most samples were obtained, and for that point may be accepted as correct. It is, however, the farthest south of all the wells, and it does not follow that the bottom at that point is the same level as the bottom at other points. On the contrary, all the evidence seems to indicate that the base of the clay series is decidedly irregular.

As the base of the clay series is approached, and after it is certainly passed, a series of beds of marked irregularity is encountered. They are prevailingly coarse-textured, and in every well include some sand or gravel. In many of the wells

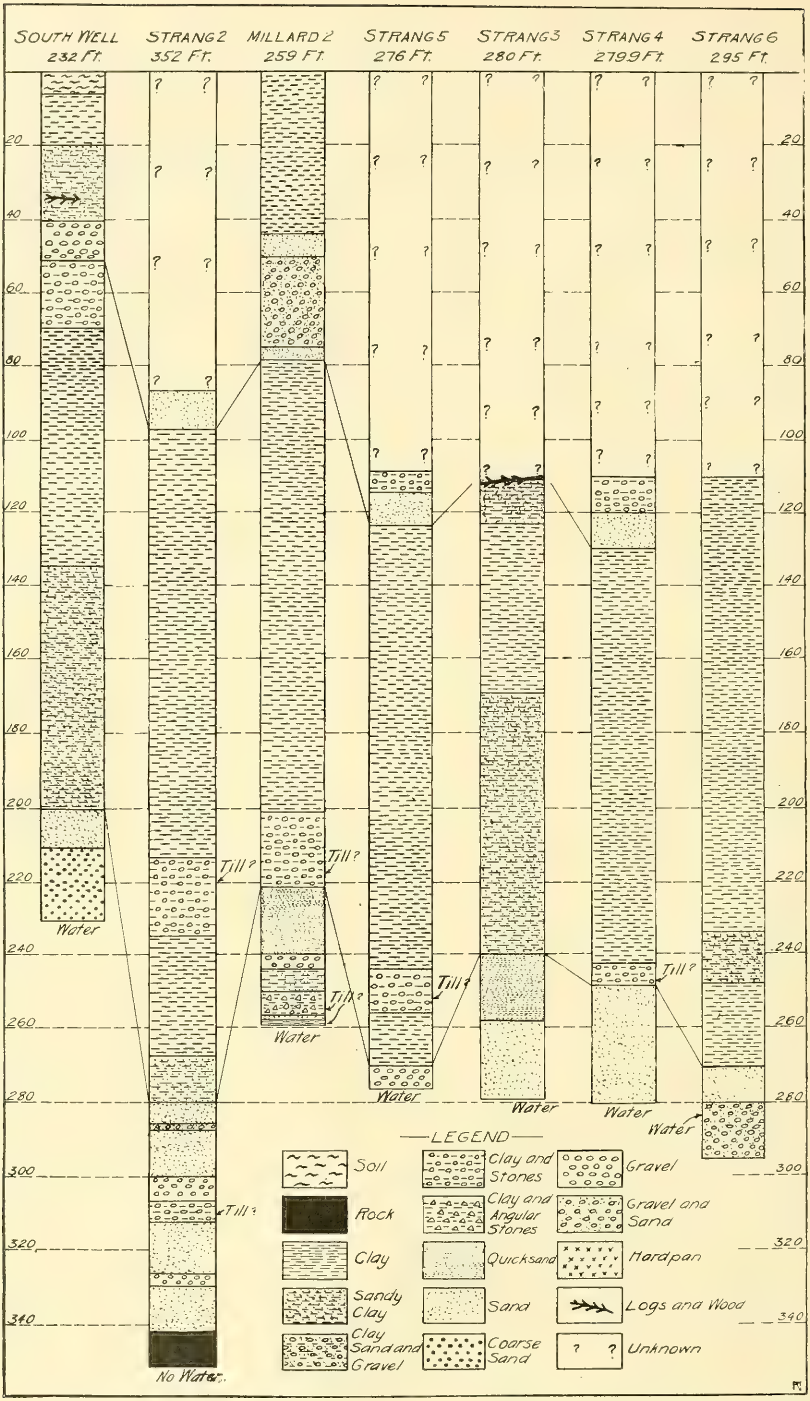


FIG. 3.—Sections of seven artesian wells grouped approximately along a north-south line. South well, southernmost. Limits of the four series of deposits indicated in a general way by the lines connecting the different sections.

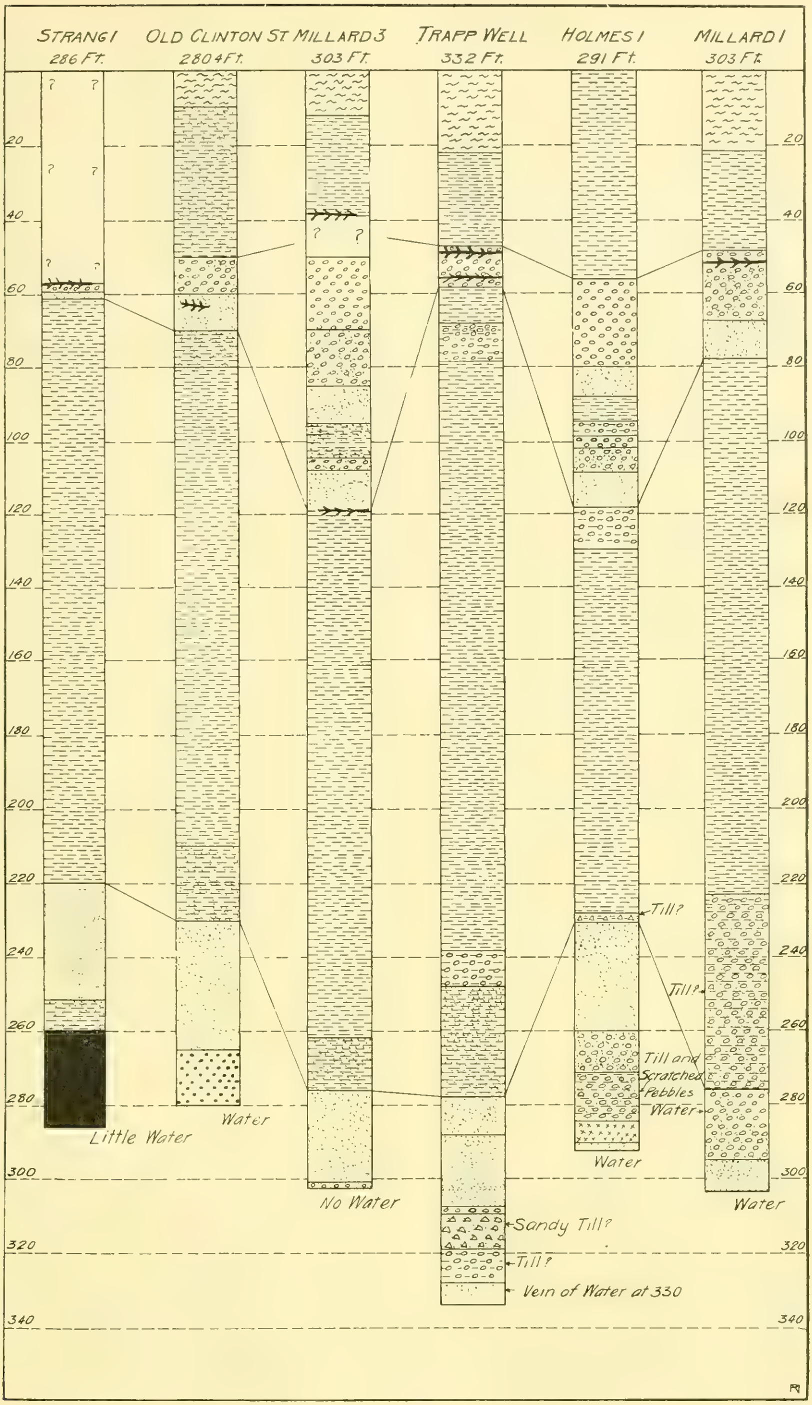


FIG. 4.—Sections of six artesian wells grouped approximately along an east-west line. Strang I, westernmost; Millard I, easternmost. Limits of the four series of deposits indicated in a general way by the lines connecting the different sections.

both sand and gravel are encountered. No two of the wells have the same sequence of layers, even though the wells are close together. Samples prove that some of the layers are water-washed sand and gravel, while others are unquestionably till, with scratched stones. In a number of other places till is suspected, though the evidence is not sufficient to prove it.

In this series of coarse deposits, water is found at varying depths in the different wells, and in different sediments. In some cases it is found in a sandy clay, called "quicksand," in which there is so much water, under such pressure, that the sand is forced into the pipes in sufficient quantities to fill them and stop the water flow. Between this extreme and that in which the water is found in coarse gravel, there are several intermediate conditions. The largest flow is obtained from the coarse gravels.

Beneath the unquestioned till, and in various places beneath the materials interpreted as probable till, is found a black sand in which from 50 to 75 per cent. of the material is quartz, the remainder being mainly dark shale fragments. In one of the wells that reached bed-rock this black sand rests on the rock, which was encountered at a depth of 342 feet. Neither here nor in the other well that reached rock, nor, in fact, in any of the wells, was any older drift encountered. All the materials are such as might have been brought by the last ice advance, or deposited since the ice-sheet melted away. Whether deposits of earlier ice advances were never made here, or whether they were all swept away by the last ice advance, is not determined by the evidence.

INTERPRETATION OF THE WELL SECTIONS.

Morainic lower series.—The history of the accumulation of the 342 feet of sediment revealed by these well-borings is in most respects clear. That the bottom series of till, sand, and gravel is morainic seems proved by several facts: (1) the neigborhood of the massive moraine which rises above the delta two miles south of the wells; (2) the position of the coarse materials at the base of the series, from all other members of which they differ decidedly; (3) the apparently irregular outline of the

upper portion of this lower series of coarse materials; (4) the marked variety of materials composing the lower series, which vary from gravel and sand to till, thus closely resembling the moraine that rises to the surface farther south; (5) the large percentage of water-washed material, again resembling the condition in the moraine farther south. This large amount of water-washed material would be expected where the ice-front stood in a deep lake, as was the case here.

Glacial lake clay.—It is well established by the evidence of various overflow channels, by well-defined elevated deltas at various levels,[1] and by lake clays on the hill slopes, that the Cayuga Valley was occupied by a steadily expanding, ice-dammed lake, with its level frequently lowered as successively lower outlets were discovered by the melting back of the receding ice-sheet. This lake condition lasted for a long time; in fact, until the Mohawk outflow was discovered. The length of this period of lake stage cannot be stated; but it was sufficient for the ice to have melted back at least forty miles. Of necessity a great amount of clay must have been deposited in this lake, not merely that supplied from the glacier, but that washed from the hill slopes, and that brought by the streams which descended the steep hill slopes.

The great thickness of clay found in all the wells, usually between the 100 and 200-foot levels, is interpreted as lake clay deposited in this ice-dammed lake. The great thickness of the clay stratum, its uniform character, its occurrence in all the wells, the general absence of animal remains and the presence of only minute fragments of plants, the occurrence of scratched pebbles that might have been ice-borne, and the increasing coarseness of the clay toward the bottom, all harmonize with this interpretation. No opposing facts were discovered.

Recent lake clays.—The uppermost clay beds, between the 0 and 40–50-foot levels, with abundant organic remains and an almost complete absence of sand and pebbles, are interpreted as lake

[1] See papers by FAIRCHILD, *Bulletin Geological Society of America*, Vol. VI (1895), pp. 353–74; Vol. X (1899), pp. 27–68; and by WATSON, *New York State Museum Report 51* (1897), Part I, r 55–r 117.

clays formed in the same manner as those now accumulating. They are believed to represent modern lake-filling similar to that now in progress at the head of the lake. When the number of torrential streams that descend the valley wall is considered, the amount of lake-filling which this stratum represents is not excessive. These streams have formed deep gorges, having not only removed much drift, but also cut deeply into the shale. The material thus removed seems ample to make this deposit.

The upper series of coarse sediments.—A much more difficult problem is presented by the sand and gravel series, sandwiched between the two clay beds, and covering an area whose length north and south is known to be over one and a quarter miles. Some widespread change in condition is here represented, indicating a stage during which clay deposit was interrupted, apparently after the ice-dammed lake ceased to offer opportunity for deposit of lake clay, and before conditions appeared which permitted the accumulation of the later lake clays.

This period of interruption of lake clay deposit must have been one in which, at the site of the wells, the conditions were either those of a shallow lake or else of absence of lake water. Both the coarseness of the sediment and the abundance of organic remains indicate this. It is inconceivable that at a distance of three-eighths of a mile (the distance from the outermost well to the nearest valley wall) gravel and sand could be deposited in a lake from 56 to 118 feet deep, especially at a point remote from the mouth of any stream. It is inconceivable, also, that gravel and sand could be deposited in such a lake over so wide an area. Nor does it seem probable that such a large number of logs would be accumulated in lake deposits. The chance discovery of seven logs in boring thirteen six-inch wells through this sand-gravel series indicates a large number of logs in the series. This point becomes all the more striking from the fact that only two logs were found in the recent lake clays, and both of these near the sand-gravel series, while no logs were encountered in the ice-dammed lake clays.

Professor Penhallow has determined the two specimens of wood preserved as follows: (1) South Well, 30–35 feet in clay,

Pinus rigida; (2) Millard Well No. 1, 50 feet, gravel, the common tamarack, *Larix americana.* Dr. Dall reports that the mollusca belong to the following genera: Valvata, Planorbis, Amnicola, and fragments of Pisidium or Sphœrium. These are

all of the same nature, namely fresh-water, and such as are found in the confervæ or other fine-textured vegetable matter, such as grow in quiet places in the course of brooks, or in ponds or lakes at the mouth of brooks. They would hardly be found in the unsheltered waters of a large lake like Lake Erie.

Correlation of coarse sediments with Iroquois stage.—The evidence seems conclusive that these sands and gravels were either shallow-water, lake-margin deposits or else stream-made land deposits, and that they were succeeded by lake conditions. In seeking for an explanation of these phenomena, land-tilting seems the only rational hypothesis. It is a well-known fact, as clearly shown by Dr. Gilbert, that the land has been tilted in this region since the deposit of the beaches of the Iroquois shore line. The Iroquois lake stage immediately succeeded the stage of ice-dammed lake in Cayuga Valley. Therefore these sands and gravels are in the right position for correlation with the Iroquois beach stage.

In a letter to me Dr. Gilbert supplies the following information: Correlating the upper bar at Richland Junction (563 feet) with the lowest bar at Weedsport, there is a gradient of 2.9 feet per mile. Correlating the upper Richland bar with the lower cut terrace at Montezuma, there is a gradient of 2.6 feet per mile. Correlating the upper Richland bar with a bar at Cayuga, there is a gradient of 2.7 feet per mile.

The lines on which these measurements are made do not precisely correspond with the direction of greatest slope of the plane of deformation, but I judge that the line from Union Springs to Ithaca makes about the same angle with the direction of greatest slope, so that these figures might be applied without correction. A correction for direction would increase the estimates for gradient.

From Union Springs, where the Iroquois beach disappears beneath Lake Cayuga, to the site of the wells is approximately twenty-nine miles; and, taking 2.7 feet per mile as a gradient, the Iroquois shore line might be expected to appear at Ithaca at a depth below present lake-level of about 78 feet. Several of

the wells passed through coarse material at this depth, and in several of them the coarse materials reach a much greater depth than this. On the other hand, the records of four of the wells show that the sands and gravels were passed through before that depth was reached. In his letter Dr. Gilbert makes this further statement:

> From Richland northward to Adams Center the gradient is 4.3 feet per mile, and north of Adams Center it is still steeper. So it is possible that a correction might advantageously be applied to southward flattening of gradient.

Some such correction, the exact amount of which is not clear, would seem to harmonize better with the distribution of the gravels as revealed by the well sections.

Several facts, as follows, seem to warrant correlation of these deposits with the Iroquois stage: (1) the difficulty of otherwise explaining the sand-gravel series; (2) the evidence of coarseness of material, and of plant and animal remains, all of which point either to land or shallow-water conditions; (3) the position of the series, resting on deposits which appear to have been completed just before the Iroquois stage; (4) and the fact that their position is approximately at the level to be expected on the theory of formation during the Iroquois stage. No facts opposing this correlation are known, and no other rational explanation suggests itself. It is therefore proposed as an interpretation of the phenomena.

SUMMARY OF EVENTS.

On the basis of these interpretations, we have revealed the following postglacial history of the Ithaca delta: First moraine was formed while the ice-front stood in a deep lake, in which the morainic material was largely assorted. After this stage there was a long period of lake clay deposit in an ice-dammed lake whose area was expanded, while its level fell by successive drops to lower levels as the steady melting back of the ice-front discovered lower and lower outlets to the north. In this lake there was floating ice, but little, if any, animal life. When the Mohawk outlet was finally discovered the ice-dammed lake nearly, if not quite, disappeared from the site of the artesian wells. The

land surface at the site of these wells was then from 60 to 120 feet below the present delta surface; but, owing to the depression of the land in the north, the lake waters either could not then reach this far, or, if they did, produced only a shallow lake. At this stage trees grew and mollusca thrived, while a series of sand and gravel layers were laid down whose depth in the several wells varies from 20 to 70 feet.

Elevation of the land in the north tilted the basin of Lake Cayuga faster than the deposit of sand and gravel was made, ultimately covering the coarse deposits with lake water. Some of the sand and gravel may be due to the work of the lake waves as the tilting of the land caused an encroachment of Lake Cayuga farther and farther south. The fact that the present surface of the delta contains no sand and gravel excepting near the stream mouths, may be explained as follows: (1) the levelness of the delta; (2) the recency of the delta—it is still so swampy at the well sites that it is flooded at least once each year; (3) the fact that the streams now bring less material, having already cut through the drift into the rock.

SOURCE OF THE ARTESIAN WATER.

It is believed that the source of the water in the upper gravels is the alluvial fans opposite the mouths of the streams that descend to the Ithaca delta. Into these fans much of the stream water sinks, in some cases entirely disappearing at all times excepting in periods of flood. It is not absolutely certain that the gravels of the alluvial fans are continuous with the sand-gravel series encountered in the shallower artesian wells; but this is to be expected, since the conditions which favor the deposit of coarse sediment must have existed continuously near the mouths of the streams that descend the hill slope. Some such source near at hand is indicated by several facts: (1) a reported variability in volume; (2) the moderate pressure of the wells, which in some cases barely forces the water from the ground; (3) the composition of the water, which indicates a shorter underground journey than that of the water in the deep wells; (4) the marked difference in composition and purity of the water from various wells.

For the water found in the deeper sands and gravels the source is believed to be the moraine which occupies the Cayuga Valley from the divide nearly to the well sites, a distance of over eleven miles. Numerous streams descend to this moraine, supplying much more water for percolation than the mere rainfall. The moraine is to a very large degree made of sand and gravel, offering the best of conditions for the entrance of water. The hardness of the water and the temperature (52° in August and December) both indicate a long underground journey; and the great pressure, which forces from one of the wells a steady volume of 300,000 gallons a day, also indicates some fairly distant source. To account for the pressure observed it is necessary to find a source much higher than the well sites. No such source is to be found to the north because the lake occupies that region; to the east and the west rise high hills in which are nearly horizontal strata of shale and sandstone. This leaves the moraine to the south as the only possible source of the water; and this source is not only ample, but, if the above interpretation of the well sections is correct, there is a direct connection between the surface moraine and the buried moraine gravels which supply the water.

R. S. Tarr.

Ithaca, N. Y.

THE RÔLE OF POSSIBLE EUTECTICS IN ROCK MAGMAS.

THE appearance of Professional Paper No. 18, *The Chemical Composition of Igneous Rocks, Expressed by Means of Diagrams*, by Professor Iddings, completes a trilogy of works[1] which will leave a permanent impression upon the nomenclature and progress of petrography. No one who has not done a little work of the sort can begin to conceive of the amount of labor employed in the comparatively small paper of less than one hundred pages which has just appeared. And even so, it is probable that vastly more in the way of experiment in trying to group the facts in different arrangements has been done, of which no trace remains. We see the finished railroad survey, and can form some conception of the engineering, but we cannot know how many lines may have been run through the dense forests before settling upon the final track.

It is easy also to notice possible improvements in the track when it is once completed; and if I make some suggestions along this line, it is only with the greatest respect for the distinguished authors of the new chemical classification. Whatever modifications the future may have in store, I think that there will be much of their work which will endure, and that such terms as "persalic" and "dofemic" will after a little become household words to the petrographers of all countries. I think the remark of Mr. Iddings, that we must look upon a rock as the chemist looks upon a solidified mass of mixed salts, that "we must think of the study of igneous rocks, their magmas and relationships, as purely physico-chemical problems, involving the measurement and comparison of mass and force, and their definite quantitative expression," as one of very great importance. When he goes on to say that there are no recognizable groupings of

[1] *The Quantitative Classification of Igneous Rocks*, by CROSS, IDDINGS, PIRSSON, AND WASHINGTON, and Professional Paper No. 14 by WASHINGTON, being the two previous works.

rocks or noticeable subdivisions of chemical series, that chemically similar rocks occur in genetically different families, that it follows that the subdivisions of all igneous rocks into groups for the purpose of classification must be on arbitrarily chosen lines, and that it is no argument against a classification if a rock of great importance belongs on the boundary of a classificatory division, that any system of classification will be as natural as any other system, he is rather too pessimistic. Merely as a mass of mixed salts, there are certain common relationships which hold, and of which any system of classification, the new one included, must take account. He has pointed out a number of such facts: (1) In the great majority of rocks alkalis do not exist in excess of that required to make feldspar or nephelite; (2) The commonest rocks are in composition like the average of all rocks which has the silica percentage of 58.7 to 59.77 and an alkali-silica ratio of 0.083 to 0.088. Iddings, in fact, suggests the possibility that all rocks have been derived from one common magma by splitting. If so, this splitting must have gone on under chemical and physical laws which are to be traced and followed in the classification. There is, however, another possibility which I wish to suggest, namely, that in the process of splitting there is a tendency in one of the fractions toward that same common average.[1] To this point we will return later. There are numerous other facts which Iddings points out, such as the inverse relation between silica and alkalis, and iron and magnesia, and various other notes on pp. 19, 64, 65, 70–81, of which any classification may take account, as, in fact, the new one does, to a very large degree. Upon that depends its serviceability. The fact that there are exceptions does not invalidate the importance of this relation, provided they are not too many.

Now, if one looks over the general diagram, Plate I, which Iddings has prepared to see that it is true that there is "no clustering of analyses" and "no natural subdivisions" (p. 17), I cannot agree with him in the conclusion he draws. In the first place,

[1] This would fit especially well in a planetesimal theory; in fact, would be almost necessary in view of the wide prevalence of basaltic magmas.

as he himself has pointed out, there are no more alkalis in most rocks than alumina and silica to go with them. In the second place, there are very few rocks with high silica percentage down about to the point representing the average rock in which the ratio of alkali-silica is less than 0.04. As the amount of alkalis increases, the number of analyses becomes more numerous. Somewhere between the ratios 0.08 to 0.09 they are most abundant. After that they diminish somewhat and become less up to a ratio between 0.12 and 0.16, and then they become more numerous once more. If we suppose this not to be accidental, we must assume *a tendency on the part of a certain group of magmas toward an alkali-silica ratio between 0.08 and 0.09.* I fixed on 0.083 from the diagram. This, I noted, was the ratio of the average rock. Expressing this in fractions, the alkali-silica ratio would be 1:12. This suggested to me at once a combination of orthoclase or albite and quartz with equal molecular proportions of silica. This again reminded me of Rosenbusch's spherulite-forming microfelsite, which he supposes to be of the composition $K_2O \cdot Al_2O_3 \cdot x\ SiO_2$, with x greater than 6. It is also the composition of micropegmatite where the quartz and feldspar are equal. All these facts harmonize with the supposition that the combination $(Na_2O, K_2O) \cdot Al_2O_3 \cdot 6SiO_2 + 6SiO_2$ is the eutectic ratio of alkali and silica. If such magmas are composed mainly of alkalis, alumina, and silica, these will tend to crystallize out whichever of these components happens to be in excess, and the analyst will be likely in the long run to obtain more analyses near this ratio than either above or below. This supposition is obviously compatible with the idea that the igneous rocks are derived from fusion either of pre-existing sedimentaries or of planetesimals.

We have remarked that down to where silica equals 0.59 and 0.57 there seems to be a belt of analyses having about this ratio, with comparatively few as the ratio dropped. Now, of course, these rocks are not all simply feldspar and quartz. How do we explain this belt or line? Simply by supposing that this eutectic relation holds, even though other elements were combined with the silica, that the 6 silica may be more or

less in combination with other elements commonly occurring in rocks, and yet that the eutectic ratio of alkali:silica :: 1:12 would hold true. Possibly it must be in combination with H_2O or some other oxide.

The first element, of course, to be considered would be the lime. What composition of albite and anorthite would give the same eutectic ratio? A little simple algebra proves that it is the commonest labradorite (Ab_2 An_3). Now, this feldspar is, as we all know, one of the commonest in rocks, and more easily fusible than either albite[1] or anorthite, so that it is strictly eutectic. In other words, the diagram seems to show that there is probably a eutectic series from a micropegmatite with quartz about equal to albite or orthoclase down to labradorite. If this theory is true, then there would be a tendency in rocks where the alkali-silica ratio was less than 1:12 to have the silica crystallize out first in a porphyritic way as quartz; and, on the other hand, if the alkali ratio were a little greater, there might be a tendency to have the feldspar crystallize out early, so as to bring the residual magma down to the eutectic ratio. A large excess of alkali would bring it near another eutectic. Corresponding to these would be a more or less quartzose marginal zone where the crystallization first began. That this is liable to be modified more or less by irregular changes in temperature, pressure, and environment, I need hardly add.

But what about the other elements, in particular the iron and magnesia? If silica were there in excess of the eutectic ratio, they would combine with it very easily and, such compounds being relatively insoluble in the magma, crystallize and separate out, in sharp form embedded in the eutectic compound. In harmony with this, we find some of the few analyses which are markedly below the eutectic ratio containing considerable quantities of lime, magnesia, and iron. They may be aggregates of these earlier eliminations of the magma—divergent splits. Some of them are such, I judge from the description. Moreover, the minerals formed in such magmas must have high silica ratios, be augite or enstatite rather than olivine.

[1] According to the latest researches of Doelter and others this is not so—for albite is 10° to 15° more fusible.

We have remarked that the eutectic ratio continues in a line from micropegmatite to labradorite ($Ab_2\ An_3$). This feldspar has a silica percentage of 53 and an alkali-silica ratio of 1 : 12. This is so close to the ratios of the average rock that they are within the limits of the probable error; in fact, we may say that the average rock has the same silica percentage and alkali ratio as labradorite. Now, we will notice upon the chart that once the silica falls below this ratio there is marked change in the behavior of the analyses, and they seem to stream off toward the lower right-hand corner, the alkali ratio dropping with the silica ratio. We might infer, therefore, that for rocks less silicious the eutectic ratio above given did not hold; or, rather, it may hold, so far as the alkalis are concerned, that they still find the most fusible compound $Na_2O \cdot Al_2O_3 \cdot 6\ SiO_2$, and 6 $ROSiO_2$, but that in the presence of an excess of bases there is some other equally or more fusible compound $ROSiO_2$.

This, remember, is a purely theoretic inference from laws of chemistry and Iddings's diagram. A moment's thought shows how amply it is confirmed by petrographic research. This more fusible mineral is augite. As the percentage of SiO_2 in augite is about the same as in labradorite (between 55 and 44), and cannot anywhere in the pyroxene group get above that of enstatite (60), we see why the distribution of analyses turns a square corner, and we find them quite frequently from 0.58 SiO_2 down with all kinds of alkali ratios. We may go on to ask if there is any eutectic balance between labradorite and augite. As the ratios of lime to silica and percentage of silica are practically the same in the augite and in the labradorite series, the question as to the predominance of the one or the other tendency will probably be a question of balance mainly between the femic and alkaline constituents. The femic constituents in a magma mainly of felsitic eutectic are only slightly soluble and tend to crystallize out early as magnetite, biotite, hornblende, etc., even though present in very small quantities; and even though they increase markedly in abundance, their solubility or fusibility is still small, except as they can be taken into the augite molecule. An excess of magnetite or olivine crystallizes readily.[1] The metallurgists tell us

[1] I am neglecting a lot of minor matters.

about this in their slag formulæ. Consequently, it is *a priori* probable that labradorite and augite magmas mix readily and without tendency to split; though, when they actually come to crystallize, petrographic observation teaches that the labradorite feldspar is the earlier and the augite later for the rocks on the right or lower silica side of the average rock. The reverse is true on the other side. We must remember that, so far as chemical affinities allow, the eutectic (most fusible, least solidified) magma will contain a little of every element going; and therefore we are not surprised at the complexity of the composition of the augites which are collected in the table accompanying the statement of the *Quantitative System.* The latest researches show that basaltic magmas are fusible at distinctly lower temperatures than either labradorite or augite.

Nor are we surprised that, if we draw a line from the average rock-analysis point, or that for labradorite, in the average direction in which the less silicious and less alkaline analyses diverge therefrom, it will strike the line of no alkalis at 43 per cent. SiO_2, or somewhat less; for this is not only the lowest silica percentage which augite, diallage, and the feldspar series reaches (anorthite), but the maximum for olivine.

So in the femic magmas there is a clear tendency away from extremely different percentages of iron, lime, or magnesia. Probably the ratio $CaO : MgO : FeO :: 2 : 1 : 1$ is not far from the eutectic one. In the following group of analyses from Lighthouse Point, for instance, it is clear that at the center, where there was opportunity for differentiation and adjustment of the magma, and the eutectic would accumulate, there is more lime than at the quickly chilled and cooled contact. The magma had an excess of magnesia and iron for eutectic relations, and this is shown petrographically by an early generation of olivine and magnetite.

Returning to the Iddings's diagrams, it seems, from a study of the distribution of Class I, that a few rocks are included (anorthosites, canadases) which it goes against the grain to include — rocks with an unusual amount of lime, but really tributary to the femic eutectic; that the real natural family is from

ANALYSES OF STONE FROM LIGHTHOUSE POINT, UNDER DIRECTION OF E. D. CAMPBELL, BY E. E. WARE, JUNE 30, 1903.

Distance from Margin	Contact		616 mm (2.2 feet)		4,115 mm (13.5 feet)		7,600 mm (24.9 feet)	
	No. 1	Molecule	No. 3	Molecule	No. 6	Molecule	No. 8	Molecule
SiO_2	46.98	0.783	47.67	0.795	47.25	0.787	47.10	0.785
Al_2O_3	17.85	0.175	17.55	0.172	18.00	0.176	17.47	0.172
Fe_2O_3	3.13	0.019	2.51	0.016	2.21	0.014	2.66	0.017
FeO	10.30	0.143	12.59	0.175	12.42	0.172	12.93	0.179
MgO	(a)7.10	0.177	5.65	0.141	6.35	0.159	6.88	0.172
CaO	(a)8.47	0.152	10.75	0.192	11.45	0.204	10.27	0.183
Sodium oxide	2.04	0.033	2.21	0.035	1.96	0.031	1.91	0.031
Potassium oxide	0.60	0.006	0.65	0.007	0.66	0.007	0.59	0.006
H_2O at above 800° C	(b)1.97	0.168	0.35	0.112	....	.....	....	.....
H_2O at 110° C	(a)1.55	0.086	0.40	0.028	....	.....	....	.....
CO_2	0.20	0.005	0.18	0.004	....	.....	....	.....
P_2O_5	0.143	0.001	0.169	0.001	0.158	0.001	0.161	0.001
S	0.097	0.003	0.183	0.0057	0.086	0.0027	0.111	0.003
Cl	0.07	0.002	0.05	0.0014	0.02	0.0006	0.09	0.0025
MnO	0.26	0.003	0.19	0.003	0.18	0.003	0.15	0.002
	100.760		101.102		100.744		100.322	
Ratio, alkalis: SiO_2	0.048		0.053		0.0483		0.0472	
Ratio, pore space: solid space, in gasolene	0.0473		0.0012		0.0032		0.0018	
Sp. Gr. in gasolene	2.83		3.02		3.01		3.02	

(*a*) Checked later in another sample.
(*b*) Determined on new sample, first method incorrect.

labradorose as a limit up; and that those which occur with more than 30 per cent. of magma belonging to the femic eutectic are rare.

Moreover, it will be noted that there is among the orders between orders 4 and 5 a new principle of classification introduced. This corresponds approximately to the extra alkaline eutectics. Similarly, the rockallases appear very isolated and strange in the salfemic family.

I shall not, however, pretend to discuss the analcitic, melilitic, and other alkaline eutectic magmas, with which Iddings is much better acquainted than I. My object is rather to suggest that ultimately a more rational and natural, and therefore useful, classification of analyses might be attained if our main magmatic groups were defined by the eutectic within whose influence they come, so that in splitting one part will be nearer the eutectic and the other farther from it. I have Iddings's diagram to thank for this suggestion.

I am not going to say all that might be said about such intergrowths as perthite and sigterite (nepheline-albite), and other pegmatitic intergrowths as keys to eutectic proportions, because I do not wish to write a treatise, but rather a review—I fear too long—pointing out what seems to me inferences to be drawn from Iddings's diagrams. But the loss of mineralizers might change the eutectic. For instance, if the eutectic be $Na_2O \cdot Al_2O_3 + 6\,SiO_2 + 6\,H_2O \cdot SiO_2$, a loss of H_2O might mean the replacement of the H_2O by $\frac{1}{2}(CaO \cdot Al_2\,O_3)$ which might be a chemical quantitative change entirely worthy of recognition in a quantitative chemical classification, *if* it proved of sufficient importance; as much so as any magmatic split.

I think that the indications of Iddings's diagrams are that it is not from a quantitative chemical standpoint of primary importance, although his figures take no account of the water. It is not to be forgotton that in a holocrystalline rock the H_2O of the magma, while it may be in combination in biotite, analcite, etc., is very likely to be concentrated in drusic and microdrusic cavities, and not be noticed in the analyses at all, or, if at all, then in the water given off below $110°$; but a maximum idea of this quantity may, however, be derived from the porosity, which in the dike mentioned above is for the more crystalline part less than a third of 1 per cent.

While, therefore, Iddings's diagrams do suggest a natural grouping and classification based on the various eutectics of various magmas, yet the time is not yet ripe for such a permanent arrangement. We do not know enough about the eutectics. In the meantime, the new system of pigeon holes has some advantages, and many, especially of the minor groups, may endure.

Still we can see that the old divisions of rocks might be grouped around the average rock and given a more precise chemical meaning, as follows:

1. Acid, *i. e.*, alkali-silica ratio 0.013 –, and silica percentage 0.58+, or limited as in diagram, eutectic ratio toward which crystallization takes place, alkali : SiO_2 : : 1 : 12.

Granites and diorites, and many syenites.

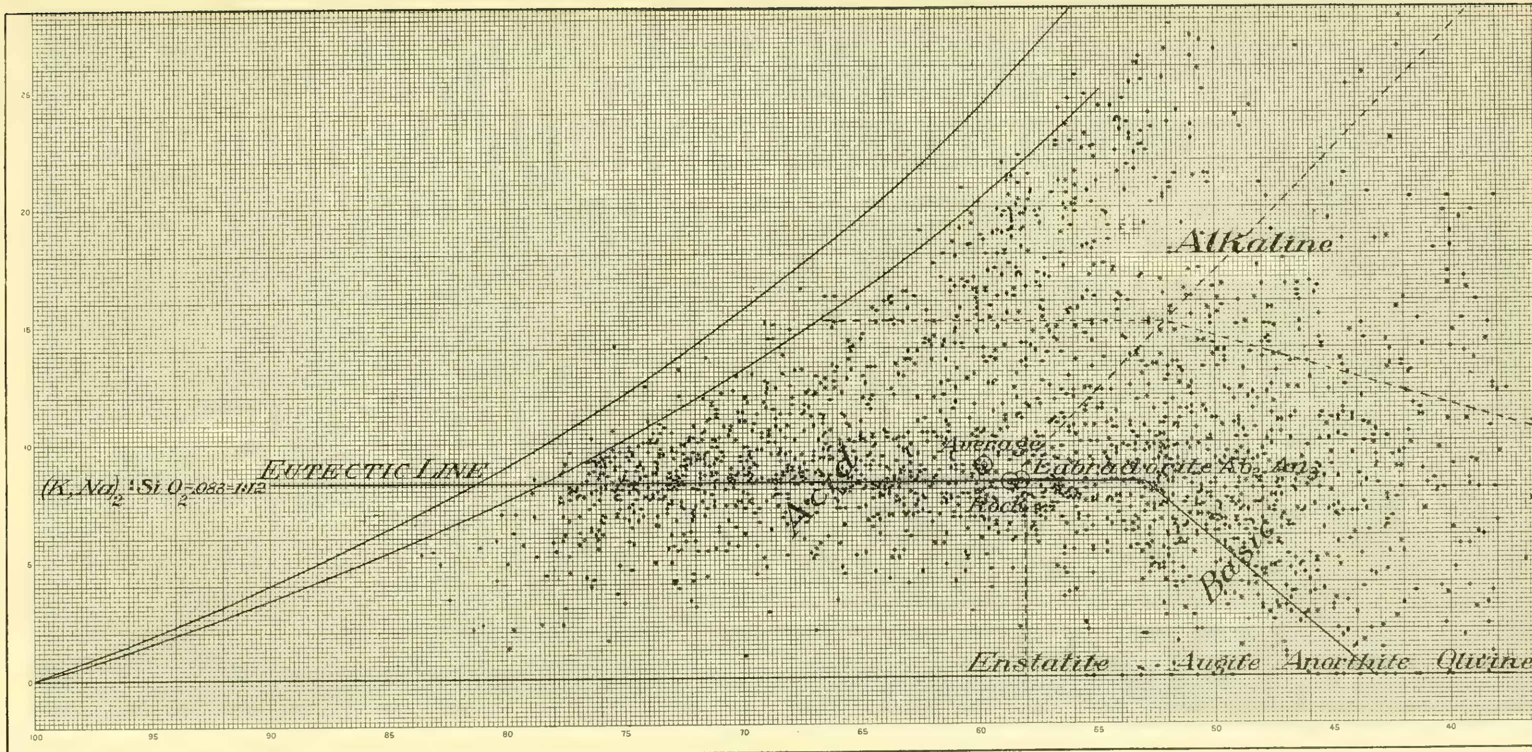


Diagram modified from Iddings's Plate I to show the natural clustering along the main eutectic line, and the possibility of a natural quantitative chemical classification of the igneous rocks.

The general rules for computing the norm of a rock can be simplified if made applicable only to this division.

2. Basic. Silica percentage, 0.58—, bounded, as shown on diagram perhaps, or by some other line expressing the fact that the eutectic is not melilite, but augite. Eutectic ratio, Ca : (Mg : Fe) : SiO_2 : : 1 : 1 : 2.

Basalts, gabbros, peridotites, etc. Computing the place of such rocks in a quantitative system is quite simple. All the alumina can be combined with potash, soda, and sufficient lime and counted salic, everything else femic, so that the ratio sal : fem is quickly found, and the ratio of soda to potash and alkalis to lime are found incidentally.

3. Alkaline. All other rocks, which obviously should also be subdivided, perhaps, as shown in the diagram, into a femic and salic group, and farther yet.

What ought to be done is carefully to study the whole field, with due regard to magmatic splitting, watching the last crystallization, and determine as nearly as may be what are the eutectic ratios in the silicate magmas. Then the work should be experimentally verified, in the new geological laboratory that I hope we are to have. Then, finally, we shall no longer have to envy the metallographist,[1] who measures the areas of micropegmatite (eutectic) copper and copper oxide, and areas of solid copper, and says: "So much eutectic with 3.45 per cent. Cu_2O, and so much plain copper: there must be just so much copper and so much oxygen."

In such study it is the last-formed minerals, with a little of nearly everything in their molecule, which show by their composition the eutectic proportions of the different constituents.

Since writing the above I have noticed in the *Beilage Band* XVII of the *Neues Jahrbuch*, p. 516, and especially pp. 546–64, an article by Schweig, and in the *Centralblatt*, 1903, p. 605, a note by Linck on a series of experiments exactly along the line

[1] HOFMAN, GREEN, AND YERXA, "A Laboratory Study of the Stages in the Refining of Copper," *Transactions of the American Institute of Mining Engineers*, October, 1903.

suggested, and in part only confirmatory of the suggestions above. For instance, Linck (pp. 606, 607) found a magma with 49.05 SiO_2 and an alkali silica ratio of 0.115, after absorbing all the silica it could at 1300° C. change to a magma with 52.20 SiO_2 and an alkali silica ratio of 0.082, almost precisely on the supposed eutectic line. Another with 62.62 per cent. silica absorbed a mixture of ferrous and ferric iron until the silica percentage dropped to 60.58 and the magma could be nearly expressed as $(NaK)_2O \cdot Al_2O_3 \cdot 6\ SiO_2 + \frac{1}{2}\ CaO \cdot Al_2O_3 \cdot 2\ SiO_3 + 3\ (Ca\ Mg, FeO)\ SiO_2$.

In Schweig's extensive series of experiments, starting with a strongly alkaline magma (17.5 per cent. alkali molecules), then adding separately silica, alumina, iron, magnesia, and lime to saturation, and then later adding also silica to saturation with the other oxide, only in case silica is added to saturation do we find analyses which are comparable with any of the rock analyses plotted by Iddings. The inference is suggested that the natural igneous magmas of the alkaline group are always able to absorb all the silica they will take.

When magnesia or iron oxide or alumina is added with the silica the alkali-silica ratio drops only to about 0.15. But the magma is much more capable of absorbing lime, and after saturation with lime and silica the alkali-silica ratio becomes 0.895 and the SiO_2 70 per cent., bring it well into the eutectic belt, which apparently therefore is that of magmas saturated with lime and silica.

All the glasses were cooled as quickly as possible, and no attempt was made to determine the temperatures of solidification. It would be interesting to repeat the experiments and note the latter.

ALFRED C. LANE.

LANSING, MICH.

A FRACTURE VALLEY SYSTEM.

The correspondence between the drainage system in the region north of the Yellowstone National Park and the system of fractures traversing the rocks is so striking that there can be little doubt of a causal relationship between them. The studies of de la Bèche in England, of d'Omalius and Daubrée in France, of Kjerulf and Brögger in Norway, and recently of Hobbs in Connecticut have demonstrated that in certain localities there is the closest correspondence between the valleys or drainage system and the fractures in the underlying rocks recognized as faults or joints. And Daubrée in his classic work *Études synthétiques de géologie expérimentale*, has shown how a more or less rectangular system of nearly parallel joints may be produced by torsional stress as well as by compression.

The almost universal application by geologists in former times of the idea of the controlling influence of fractures on drainage, and the exaggeration of the importance of faulting in this connection, coupled with the evident independence of many drainage courses from faulting, and their obvious dependence on other factors, led to a revulsion on the part of modern physiographers from the views of earlier geologists to such an extent that the influence of rock fractures on drainage courses has been minimized, if not altogether neglected, in recent times.

One reason for the revulsion from the idea of fracture drainage systems is to be found undoubtedly in the emphasis formerly laid on the conception of faulting as an essential element in the problem. This was introduced in the term "fault valleys," (*vallées de failles*) of d'Omalius, and has been memorialized in the vignette on the title-page of the *Annual Report of the United States Geological Survey*. That such valleys occur is well known, but that they form a small fraction of the whole is beyond dispute.

It is to be noted, however, that the demonstrations of Daubrée deal chiefly with joints or fractures (*cassures*), rather than with faults (*failles*), the two being but different phases of the same

phenomenon, fracturing; one, a result of small or imperceptible displacement; the other, of profound, or at least notable, dislocation. The torsional experiments of Daubrée produced more or less rectangular systems of nearly parallel fractures, some of which might be called joints, and others faults. The studies of Becker,[1] Van Hise,[2] and Hoskins[3] have established the laws and frequency of parallel and of conjugate joints (*systèmes conjugués* of Daubrée) and the phenomena have become familiar to all geologists who have worked in regions of well exposed disturbed rocks.

The phenomena are in part as follows: There are faults in more or less parallel lines through wide extents of territory intersected by faults at various angles often nearly 90°.

A dominant or major fault is frequently accompanied by parallel fractures of minor degree, which are in some cases close to the dominant fault, in other cases at considerable distances from it.

Faulting is accompanied in parts of its course by crushing and brecciation of the wall rocks; in other parts the sides of the fault are closely pressed together without evidences of brecciation. Further, there are portions of a fissure plane where the walls are not closely compressed, but may be actually open.

Planes of fracture and fissuring are often lines of special decomposition of the rock material, and are for this reason less resistant than the neighboring rocks.

From these facts it is evident that the course of drainage, in following lines of least resistance, may cut its way along fault lines where they are in brecciated, loosely aggregated, or decomposed rocks, but may leave the faults in places where unbroken rocks are closely compressed. Moreover, streams may find less obstacle in cutting unfractured softer rock than in removing fractured harder material.

[1] GEO. F. BECKER, *Monograph* III, *U. S. Geological Survey* (Washington 1882), pp. 156–87; *Bulletin of the Geological Society of America*, Vol. IV (1893), pp. 41–75; and *Transactions of the American Institute of Mining Engineers*, Vol. XXIV (1894), pp. 130–38.

[2] C. R. VAN HISE, *Sixteenth Annual Report, U. S. Geological Survey* (Washington, 1896), pp, 633–78.

[3] L. M. HOSKINS, *ibid.*, pp. 845–74.

Numerous parallel joints would aid erosion, if it were once located along a dominant fissure, by permitting the falling in of the sides of the drainage channels. Consequently, it is reasonable to expect that planes of fracture will in some cases become lines of drainage and pronounced erosion, while in other cases they may be disregarded by streams.

It is also known to every field worker that dislocations in large areas of massive rocks are easily overlooked, and are often difficult to determine when suspected; and further that minor fractures are generally neglected in geological field work. It follows from this that much evidence that may exist connecting the location of drainage with rock fractures has not been collected, and much that might be sought, by the very nature of the problem, may not be found, because the bottom of a valley is usually filled with loose material that conceals the rocks through which the valley has been cut.

A study of a mountainous region such as that lying north of the Yellowstone National Park must convince one that fracture systems have had more influence on the location of drainage than is ordinarily supposed, or than can be actually demonstrated, perhaps, by the evidence obtainable from the region in its present condition of rock exposure.

With regard to the presentation which follows, it is to be remarked that the problem of a possible fracture drainage system was not in mind when the writer was in the field, and no special search was made for evidence bearing on the question. The argument offered is based on such observations on the structure of the region as were made in the field by Mr. W. H. Weed and the writer, and on the drainage features of the map prepared by the topographers.

The topographic map which is reproduced is a reduction of that of the Livingston Quadrangle, Folio 1 of the *Geologic Atlas of the United States.* The geology of the district may be found in the folio. In this connection the map of the Three Forks Quadrangle Folio 24, and those of the Yellowstone National Park, Folio 30, should be studied.[1]

[1]U. S. Geological Survey, *Geologic Atlas of the United States*, Folio 1, Washington 1894; Folio 24 and Folio 30, 1896.

A simplified drainage map in which the drainage lines are somewhat straightened is given on the thin sheet, which is intended to be placed over the topographic map. The purpose of straightening the drainage lines is to present a simpler expression of the system, rendering the persistency of some of the directions more evident, and permitting the relationships of the various directions to be more easily noted. It does not follow that drainage channels would be more in accord with fracture systems if they were straighter. Fractures and faults are not necessarily straight. They are more often curved or crooked, as is the case with most of those observed in the region under discussion. The fault lines and dikes are printed in blue on the thin sheet. It is probable that the irregularities of direction in the drainage, as it is drawn on the topographic map, are more in accord with the fractures than the straightened lines traced on the drainage map. The value of the tracing is in the simpler expression of the system, serving the same purpose as a simplified statement of a highly complex set of relationships. It may be looked upon as a diagrammatic statement of the drainage system.

The region embraced by the map lies between the meridians 110° and 111°, and latitudes 45° and 46°. It is immediately north of the Yellowstone National Park, and contains the Snowy Range, the eastern slopes of the northern portion of the Gallatin Range, part of the Bridger Range, and the southern slopes of the Crazy Mountains. The Yellowstone River traverses the quadrangle from the south and southwest to the northeast, its tributaries intersecting the country in all directions.

A study of the topographic map reveals the angular character of much of the drainage system, and the prevalence of certain parallel and sub-parallel lines which appear in various streams and occur in quite diverse portions of their channels. Along parallel lines different streams may be flowing in opposite directions; one stream may be near its source, another near its mouth, having other portions of their channels trending in other directions. The persistency of these lines becomes more striking when the geological structure of the region is taken into account and it is observed that certain drainage lines traverse rocks of

such diverse nature as gneiss and schist, volcanic tuff breccia and solid lava, limestones, sandstones, and shales.

The relation of some of these directions of drainage to known fracture planes will be pointed out. The dominant drainage lines in the southern three-quarters of the quadrangle trend about northeast-southwest and northwest-southeast, more nearly N. 30° E. and W. 30° N., the angle between them being approximately 90°. There are other systems of almost rectangular lines somewhat differently oriented, namely, north-south and east-west. These are well developed in the central eastern part of the quadrangle.

Let us consider these systems in some detail, commencing with the main drainage channel, that of the Yellowstone River. This enters the quadrangle on the south in a curiously zigzag channel, known as the Third Canyon, cut in crystalline schists. The longer zigzag lines run northwest, and the shorter are almost at right angles. The northwest direction is followed from Gardiner to Reese Creek in Cretaceous strata, is exchanged for a more northerly direction as far as Yankee Jim, where the northwest direction is followed through a narrow gorge into the open valley, where a right-angled turn is made to the northeast. From Reese Creek to the open valley the river traverses crystalline schists.

The dominant northwest line of the river just described is parallel to the most profound fault within the region; namely, that which threw the whole sedimentary series, including the Laramie Coal Measures, down below horizons of crystalline schists. It is a fault of more than 11,000 feet and probably is more than 16,000 feet. This fault appears to end abruptly at Cinnabar Creek, the principal throw being southeast of Reese Creek.

It is interesting to observe that the Yellowstone River in no place exactly follows the fault line as it is located on the present surface. But it is evident from the topography of the country south of the river and east of Gardiner that parallel fractures must exist on both sides of the fault line, and these must control the northwest direction of the tributary streams and the longer

lines of the zigzag Third Canyon. These lines persist to the southeast within the boundary of the Yellowstone National Park, the fault itself being covered by younger volcanic lavas.

As already remarked, the great fault appears to end at Cinnabar Creek, but the Yellowstone River follows a line parallel to it through the gorge at Yankee Jim, and parallel lines of lesser drainage are plainly shown in the vicinity. Whether the fault actually ceases at Cinnabar Creek cannot be determined, because of the covering of volcanic rocks forming the surface of the mountainous country westward. Beyond these lavas, however, in a direct line a similarly profound fault is exposed in the Madison Range in the Three Forks Quadrangle. This was accompanied by a similar throw of the sedimentary strata south of the crystalline schists, and is in a direct line with the fault just described. The total length of the combined fault lines is over sixty miles.

Parallel to this great fault are several well defined ones of less extent, the largest lying north of Mill Creek Basin. Here there are two sub-parallel faults which unite in the head of the North Fork of Mill Creek. The dominant one of these has been traced from the Boulder Canyon westward to the Yellowstone Valley, a distance of twenty miles. The shorter fault has been traced for thirteen miles. They are not observed west of the Yellowstone Valley in the Gallatin Mountains because of the covering of volcanic lavas, but they appear again with the same characters in the Madison Range just west of the lavas, evidently passing beneath them. The western faults are exposed for twenty miles, and there can be no doubt of their persistence beneath the lavas. In this case the total length of the principal fault would be sixty-four miles.

In the bare gneisses two miles north of the fault line at the head of the North Fork of Mill Creek joint planes or small faults are clearly visible, parallel to the main fault and having a hade to the south, indicating normal faulting.

In other parts of the region there are faults parallel to those just described. A small one within the area of crystalline schists occurs in the southeast corner of the quadrangle, crossing

Slough Creek. It is exposed for a short distance only, being covered at both ends by volcanic rocks. A still smaller one was observed six miles farther north. These indicate the presence of fractures parallel to the profounder faults.

North of the body of crystalline schists a northwest fault exists in the valley of the East Boulder River; another is situated south of Livingston Peak; and two smaller faults occur between this mountain and Livingston. Two more are located just west of the Yellowstone River in this vicinity; and there is a short one northwest of Mount Ellis, in the central western margin of the quadrangle.

The presence of major fractures in a northwest-southeast direction being clearly established, the occurrence of parallel fractures of minor importance is rendered highly probable, some in fact, having been observed in the field.

Corresponding to these northwest-southeast fractures are the channels of many of the tributaries of Slough Creek, Buffalo Creek, and Hell Roaring Creek; the minor branches and the main channels of many of the streams flowing into the Yellowstone, as far as Livingston, notably those in the Gallatin Range. The most remarkable instance, which is a good example of a fault valley, is the valley of East Boulder River.

Returning to the consideration of the course of the Yellowstone River, it is seen that upon leaving Yankee Jim Canyon it flows at right angles through a broad valley in a northeasterly direction for forty miles. More strictly, the first twenty miles are about N. 30° E., the next sixteen miles being more northerly. From the mouth of Shields River beyond Livingston the course is south of east, nearly at right angles to its course at Livingston. This is followed by a right-angled bend at McAdows Canyon, after which the course is northeast to the edge of the quadrangle.

The broad valley of the Yellowstone between Yankee Jim Canyon and the Lower Canyon, which valley continues southwest up Tom Minor Creek, lies in the direction of a scarp fault forming the western flank of the Snowy Mountains. The summits of gneiss and schist at 11,000 and 10,000 feet from Emigrant

Peak to Mount Delano rise abruptly on the east side of the valley, while on the west there are the long sloping spurs of volcanic lavas overlying sedimentary strata in the northern part of the Gallatin Range. The location of this fault was not discovered in the field, as it is undoubtedly obscured by the valley deposits. It dies out abruptly before reaching the Lower Canyon, near Livingston, and is probably most profound north of the cross fault at Mill Creek.

This northeast direction is the same as that of two pronounced faults in the southwest corner of the quadrangle that enter it from the Yellowstone National Park. One lies in the drainage channel of Cinnabar Creek; the other is in the valley of Reese Creek. It is probable that a third fault parallel to these occurs in the valley of Gardiner River west of Mount Everts, but it has not been definitely located. These faults terminate in the great northwest fault in Yellowstone Valley south of Sheep Mountain.

The throw of the Cinnabar Creek fault is to the west, but the extent of the displacement is not determinable. It has been traced for a distance of eighteen miles. The Reese Creek fault is clearly recognizable east of Electric Peak, where the throw is to the east and the displacement more than 6,000 feet. It continues southward as a scarp fault along the east flank of the Gallatin Mountains in the Yellowstone Park. It is known for twenty miles, and disappears under lava. The throw of the fault west of Mount Everts is to the west.

A minor fault parallel to those just described occurs in the gneiss east of, and parallel to the channel of Hell Roaring Creek. Several northeast-southwest faults of slight extent have been noted north of the great body of crystalline schists. One is a short spur connected with the fault in the valley of the East Boulder River. Two are connected with the northwest-southeast faults southeast of Livingston, and another is south of Mount Ellis in the western part of the quadrangle. In each of these cases it is interesting to observe that there are conjugate faults at nearly right angles.

In the direction of the northeast-southwest fractures, besides the Yellowstone Valley and Cinnabar and Reese Creeks, which

are definitely located on fault lines, there are the channels of Bear Gulch and Crevice Gulch, Hell Roaring and Slough Creeks, with tributaries to Boulder River and Mill Creek, and the upper portion of the West Boulder.

Another conjugate system of fractures is indicated by the rectangular drainage with lines almost north-south and east-west. The direction of the main Boulder River through its canyon is the same as that of several of its head branches, of Buffalo Creek to the south, and of several north-south drainages to the east. The east-west direction is found in tributaries of the Boulder River, in the North Fork of Mill Creek, and in a stream in line with this east of East Boulder plateau. In this case there is a fault nearly parallel to the North Fork of Mill Creek connected with the northwest-southeast system of faults. An east-west fault has also been observed by Mr. W. H. Emmons near Haystack Peak at the head of Boulder River. There can be little doubt that in this portion of the quadrangle there is a system of fractures in an east-west and north-south direction.

The sculpturing of the canyons of the Boulder and West Boulder, and of several to the east, seems to require the action of other agencies than those of ordinary erosion. These narrow canyons have been cut 3,000, 4,000, and 5,000 feet into gneiss and schist within a few miles of their heads, and their drainage basins seem quite inadequate to furnish sufficient water for so great and such deep erosion. It seems as though the rocks must have been rendered more susceptible to abrasion by being fractured or jointed.

A similarly placed system of drainage channels exists in the northwestern corner of the quadrangle west of Shields River and east and south of the Bridger Range, but no system of fractures or faults has been noted in this region.

The northeastern corner of the quadrangle is intersected by a distinctly rectangular system of drainage. The channels of the Yellowstone and Boulder Rivers, with the tributaries of the Shields River, have a northern trend nearly at right angles to those of Shields River and several creeks flowing southeast from the Crazy Mountains, and numerous small tributaries of the

Yellowstone and the Boulder Rivers. That these directions are parallel to existing fractures is shown by the trend of dikes of igneous rock that traverse this part of the country. A number of dikes occur in Crow Indian Reservation on the Boulder River. They trend northwest almost exactly parallel to the small streams in this vicinity. Two longer dikes occur on Gage Creek, trending in the same direction. In the valley of Shields River there are dikes having a northeast-southwest trend. The Crazy Mountains are filled with innumerable dikes radiating in all directions from the core of igneous rocks lying north of the Livingston quadrangle. That portion of the mountains within the limits of the map is traversed by dikes trending north-south in the middle of the group, on the east side trending east of south, and on the west side trending west of south, but not parallel to the drainage channels in the foothills. Apparently these fractures are immediately connected with the intrusive core of the mountains, and have not extended into the surrounding sedimentary strata for long distances. The system of fractures indicated by the drainage is probably more profound and was produced by deeper-seated forces.

There are dikes and lines of intrusive rocks parallel to neighboring drainage channels in the vicinity of Haystack Peak, Emigrant Peak, and at the west base of Sheep Mountain.

Besides the drainage that may have been controlled or initiated by fracture lines, there are within the area covered by the map excellent examples of channels that have followed softer rocks, where the minor topographic features of the country conform to the position and character of the sedimentary strata, and where fracture and faulting appear to have had no influence on the drainage. It is the larger valleys and dominant channels that exhibit the general relationship between drainage and fracture.

That the drainage system of this quadrangle is closely related to the structural features of the rock formations will not appear surprising when the geological history of the region since Laramie times is taken into account.

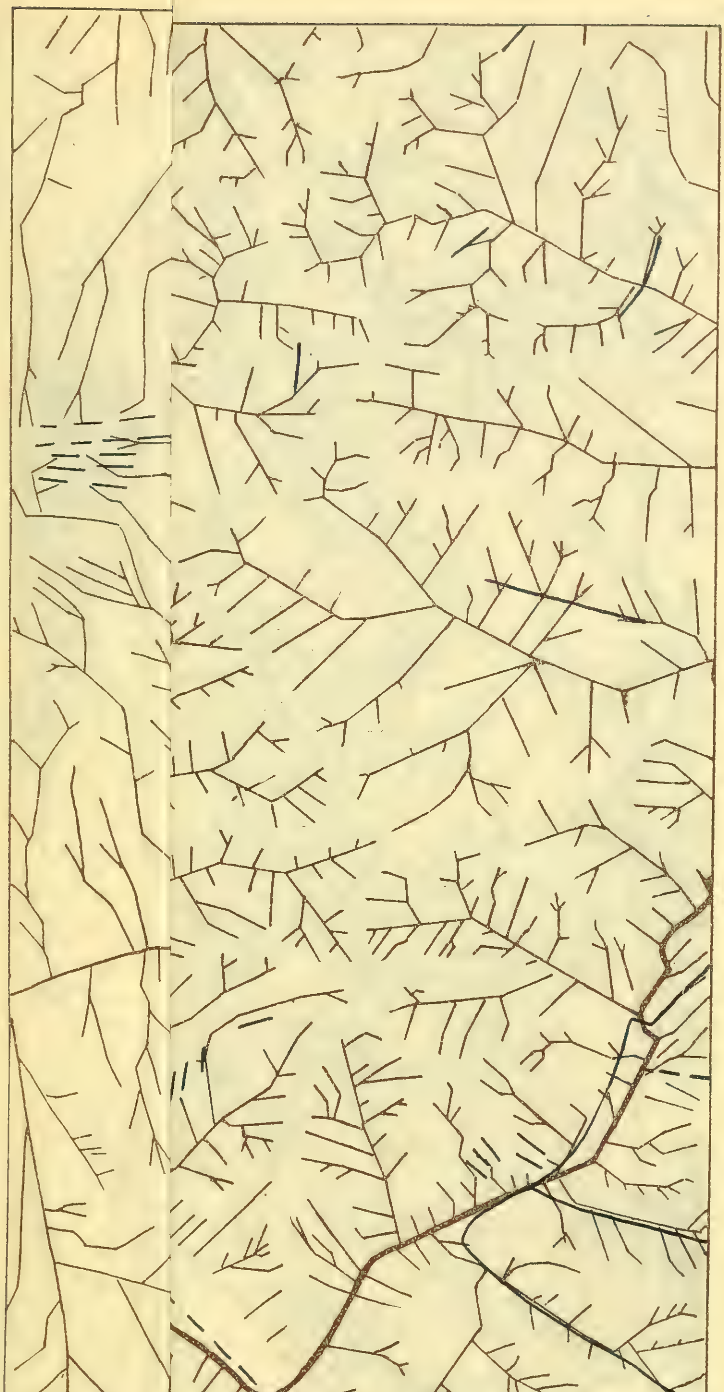
The dislocation of the crystalline schists and sedimentary strata that followed the deposition of the Laramie resulted from

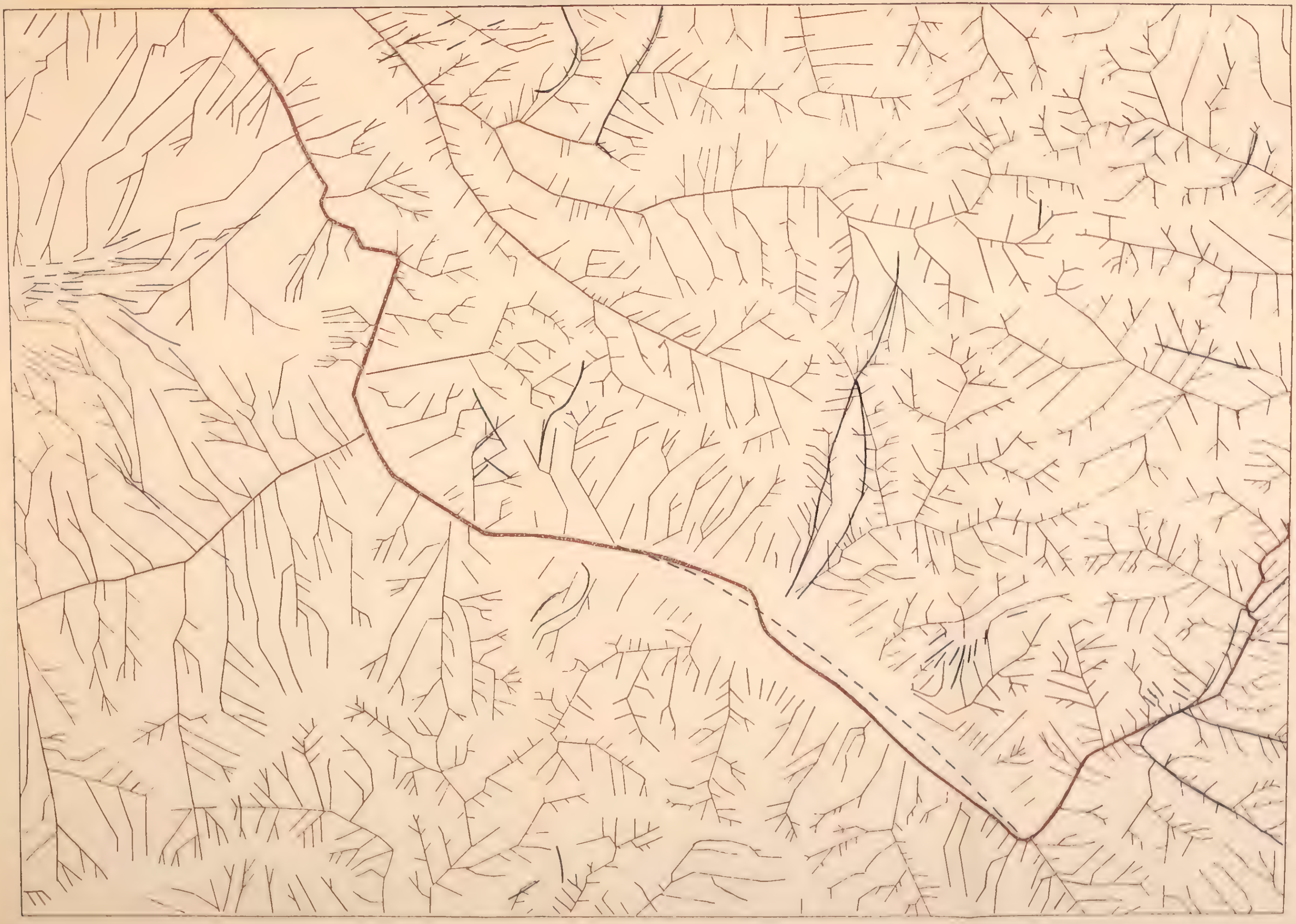
torsional shearing stresses of great magnitude, as is shown by the rapid variation in the amount of displacement along the planes of faulting. These fractures have occurred in nearly parallel planes, and also in a nearly rectangular system, and resulted in faults and joints.

The fractured and dislocated rocks were eroded to a very great extent at a very early period. Thus from a large area the entire sedimentary covering, 10,000 feet or more in thickness, was removed from the underlying crystalline schist before Eocene times, and the surface of the country presented an irregular topography not greatly different in character from that of the present day. Upon an irregular surface of crystalline schists in the present valley of the Yellowstone River, just south of the Livingston quadrangle, there rest horizontal beds of Eocene volcanic tuff with ancient tree trunks in vertical position. Erosion has reduced the rocks in this vicinity to nearly the same surface at successive periods, as is shown by the occurrence of surface extrusive lavas of very different ages in close proximity. The direction of the drainage in this locality has undoubtedly shifted repeatedly during this long lapse of time.

Since volcanic activity commenced, fracturing and faulting have taken place at intervals through the Tertiary period. The profoundest faulting and erosion took place before Eocene times and the extravasation of Eocene tuffs. This was followed by great accumulations of Miocene tuffs and lavas, which were fractured and dislocated along the faults in Cinnabar and Reese Creeks, and elsewhere. These were greatly eroded in late Tertiary time before the eruptions of Pliocene rhyolite which has been faulted in its time.

In the faulting of the Electric Peak and Sepulchre Mountain blocks there was unquestionably a displacement along the line of the earliest northwest-southeast fault against which these blocks terminate proving a recurrence of fracturing and displacement along old lines of jointing and faulting. And while there is little or no evidence in this region that successive faulting has often taken place at widely remote geological periods along the same lines, it seems probable that profound jointing may establish





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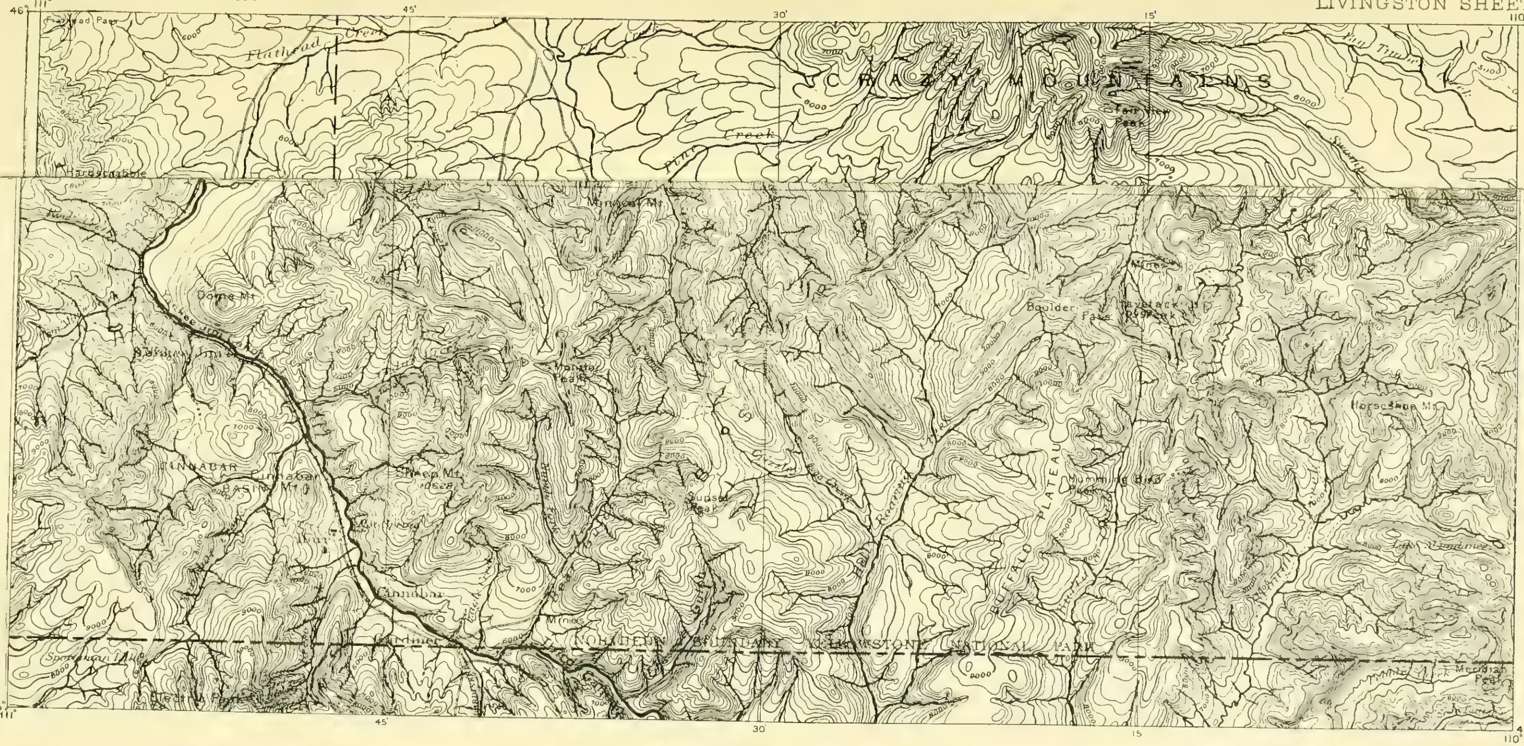
MONTANA
LIVINGSTON SHEET



Edition of Dec. 1891.

0 2 4 6 8 10 12 Miles

Contour Interval 200 feet

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Contour Interval 200 feet

planes of weakness along which subsequent movements of a minor character may take place affecting superimposed rocks, so that a system of Eocene, or even late Cretaceous, joints may be extended upward into overlying rocks in Miocene time provided similar dynamic action of a pronounced character occurs in both periods as it has in this region.

JOSEPH P. IDDINGS.

CUSPATE FORELANDS ALONG THE BAY OF QUINTE.

TABLE OF CONTENTS.

INTRODUCTION—THE BAY OF QUINTE.

THE flat-lying limestone regions immediately to the north and east of the east end of Lake Ontario are traversed by a number of deep valleys with graded side slopes on their lower courses. These valleys are probably of preglacial origin, and were carved at a time when the relative altitude of the several parts of the Ontario lowland was different from what it is at present. The partial submergence of a number of these valleys, tributary to one another, has formed the water body known as the Bay of Quinte. This bay extends from near Kingston, at the east end of Lake Ontario, toward the southwest for a distance of over fifty miles, and nowhere has it a breadth exceeding two miles. A reference to the accompanying general map will show its remarkable zigzag course.[1] For purposes of study it may be

[1] For a discussion as to the probable origin of this valley see "The Trent River System and the St. Lawrence Outlet," *Bulletin of the Geological Society of America*, Vol. XV.

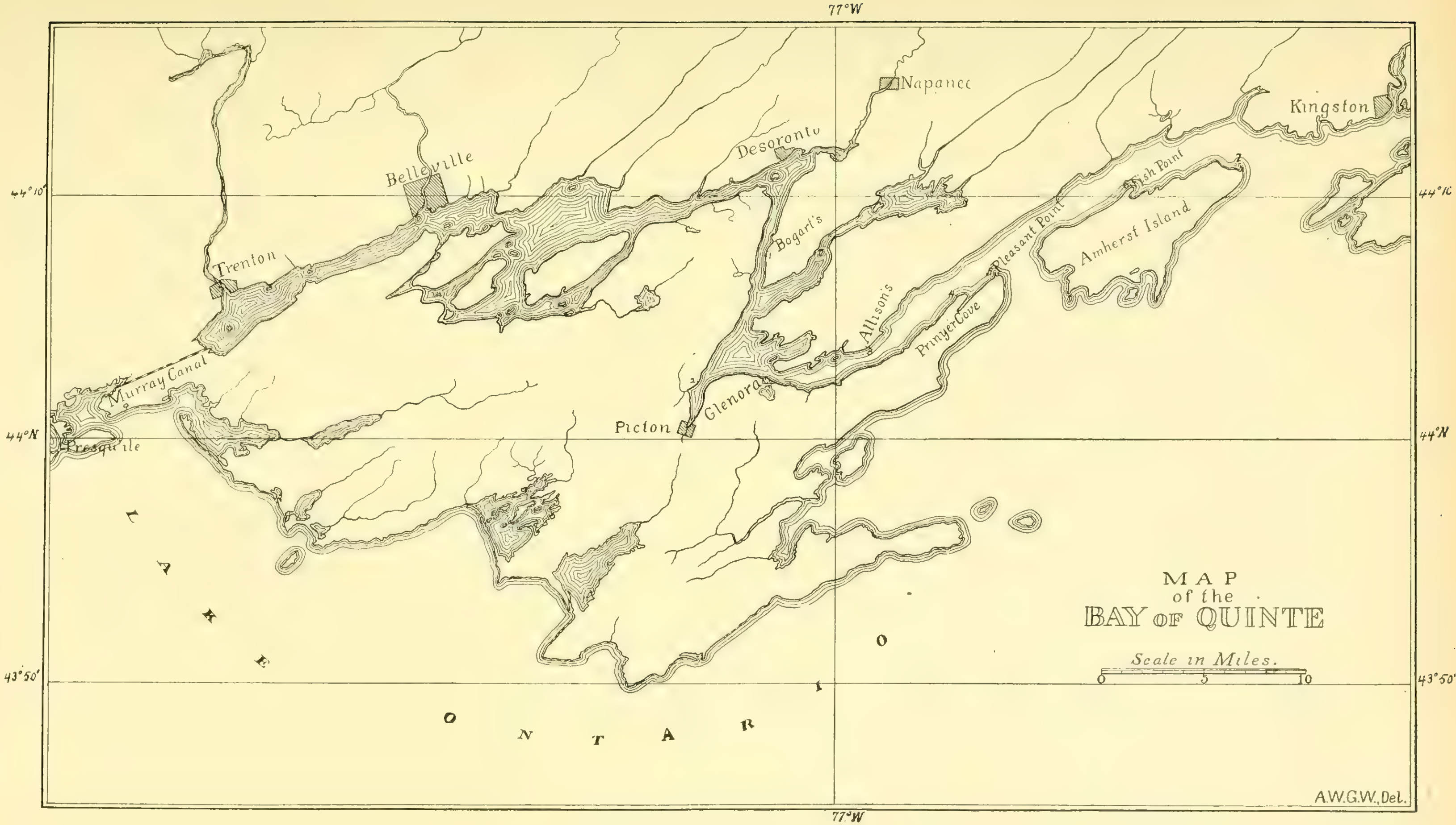
77°W
Napanee
Kingston
Desoronto
Belleville
44°10'
44°10'
Trenton
Bogart's
Fish Point
Amherst Island
Pleasant Point
Allison's
Prinyer Cove
Murray Canal
Glenora
Picton
44°N
44°N
Presqu'ile
MAP
of the
BAY OF QUINTE
Scale in Miles.
0
5
10
43°50'
43°50'
LAKE ONTARIO
A.W.G.W., Del.
77°W

FIG. 1.

divided into three parts: the Trenton-Desoronto section, trending a little north of east; the Desoronto-Picton section, trending to the west of south; and the Picton-Kingston section, trending nearly northeast.

The upper section is comparatively shallow; for the most part the shores are rocky; and no characteristic cuspate forelands have been noted along them.

The middle section, sometimes known as the Nine Mile Reach, has much deeper water, and the valley sides are steep, often inaccessible cliffs of Trenton limestone. The maximum relief is about 185 feet. Much of the shore is rocky, but along the east side there are, in places, small amounts of modified drift lying between the water's edge and the front of the adjacent escarpment. In one place, a short distance below Bogart's dock, shore drift derived from this material has formed a small foreland of fine sand which resembles the V terrace with the rimming bars which Gilbert describes as occurring on the shores of Lake Bonneville. On the west side of Picton Bay there are also two small spurs of shore drift which seem to be associated with talus cones from the face of the cliff.

Along the third section of the bay there are four excellent examples of the cuspate foreland and one long flying spit. Some of these cuspate forelands have a remarkably close resemblance to the V terraces and V bars of Lake Bonneville. Parts of the shores of this section of the bay are also rocky, but the amount of drift, both till and stratified material, is greater than elsewhere. Off the west end of Amherst Island the water has its maximum depth of 230 feet. The valley reaches its maximum relief of 284 feet near Glenora. The south shore is bordered by the steep escarpment of a cuesta which rises about 200 feet above water level near Glenora. The height gradually decreases eastward, and in Amherst Island it is only about 50 feet. The north shore rises gently inland. On the south shore rock exposures are numerous; on the north shore glacial drift frequently occurs, bed-rock less often. Of the four cuspate forelands to be described, three occur on the south shore; the flying spit is located at the extreme eastern end of Amherst Island, also on the south side of the bay.

The material which forms the loose débris of the shore is in part derived from the wasting of the cliffs, in part from the glacial deposits. The material which forms the single spit which occurs on the east side of the middle section, and also that of the spit which occurs on the north side of the eastern section of the bay, seem to be wholly of glacial origin. The materials of the three forelands and the flying spit which occur along the south side of the eastern section of the bay are largely derived from the bed-rock where it outcrops along the shore, but there is a slight admixture of gravels derived from the glacial deposits.

MOVEMENTS OF THE WATERS OF THE BAY OF QUINTE.

Currents.—Before describing each of the spits in detail, and discussing the question of their origin, it is considered advisable to say a word about the movements of the waters of the bay. As is well known, there are no appreciable tides on the Great Lakes; hence tidal currents do not enter as a factor in the distribution of shore waste. The volume of water discharged by tributary streams into the upper part of this bay is considerable, but its ratio to the total amount of water in the bay is so small that no appreciable outflowing currents are set up. It is altogether doubtful that any portion of the bay water below Deseronto has a normal current from this cause of over a mile per day.

The seiches of Lake Ontario periodically affect the height of the water of Kingston. Accurate data are not at hand to permit of any statement of their exact periodicity, but by calculation it should be about sixteen hours between wave-crests. The change at Kingston ordinarily does not exceed a foot and a half, except during and after exceptional storms, when it is much greater. The water that is backed into the bay at the time the crest of the seiche-wave is at Kingston must theoretically cause an oscillatory movement in the bay, as the crest and trough of the seiche-wave travel up the bay. At Napanee, at the head of the navigable portion of the Napanee River, about seven miles above Desoronto, this seiche-wave often makes a difference in water level of about 3 feet. Here, however, the water is backed

into a narrow funnel-shaped opening. Out on the open bay very slight changes in level are occasionally noticeable, but no records of their amounts are available. It may, however, be stated that they are very slight, and at no time, except at the upper part of the Napanee estuary has the writer been able to determine the existence of any noticeable current due to this cause. It may be stated that the currents in the bay produced by this cause are not capable themselves of transporting any of the material which is moved along the bay shore. It is true that they may slightly accelerate or retard the currents which are concerned in the active transportation, but they are much too weak to be in any way considered as active and effective agents in transportation. Where they have been observed at their maximum the water is perfectly clear, although the bottom is covered with a fine mud which settles rapidly when stirred.

Approximate estimates as to the strength and importance of the seiche currents can also be made at the Murray Canal. This canal is four miles in length and connects the upper end of the bay with Presqu'Isle Bay, this latter bay connecting directly with the open lake. The crest of the seiche reaches Presqu'-Isle Bay some hours before it reaches Kingston. Consequent on the rising of the waters at Presqu'Isle Bay a current sets in eastward through the canal to the head of the Bay of Quinte. Some hours later the crest of the wave advancing from the Kingston end of the bay, having had about 110 miles farther to travel, reaches the head of the bay, and occasionally may start a current through the canal in the opposite direction. Unfortunately, it has not been possible to carry on simultaneous observations at several points on the bay, nor at any one point continuously for a long enough period to establish the time relations of these oscillations. The existence of the currents through the canal has been established. These currents in the canal are farther complicated by wind-action which generates surface currents. From observations made during periods of calm weather the author would infer that the current to be attributed to the seiche alone rarely exceeds five miles per day. It must be noted that until careful quantitative observations are made there can be

no definite statement, for even during calm weather the momentum of wind-generated currents causes them to continue for a considerable period, and it is difficult to distinguish positively between these residual currents and the true seiche current.

In the absence of accurate observations of the time of oscillation of the seiche, we have no means of knowing whether the crest of one wave starts the currents through the canal from one direction at the time when the trough of another is at the opposite end of the canal; in other words, we do not know whether the current periodically reaches its greatest possible maximum value. Assuming a mean depth in Lake Ontario of 65 feet, and making some allowance for retardation of the advance of the wave-crest up the narrow bay, a calculation of the time of oscillation of the seiche along the line of direction of the most prevalent storms suggests that the periodicity of coincidence of crest and hollow at opposite ends of the canal will not be the same as the period of the seiche.

The mean depth of the canal is 11 feet; the breadth at the bottom, 80 feet; the breadth of the water surface, 125 feet. It may be inferred from the small volume of water moved through the canal by the seiche current that in the much broader, deeper bay the actual currents generated by the seiche oscillation must be very slight.

Waves.—The effective agents in the transportation of the shore débris are wind-waves, and the longshore currents which are associated with them. The size of the material transported and the rate at which it travels must necessarily depend upon the strength of the waves; these in turn depend upon wind velocity, and, in the Bay of Quinte, upon wind direction. Observations which have extended over a considerable period have shown that resultant effective transportation along the shores of the Great Lakes depends in part upon the direction of the most prevalent winds, in part upon the length of the stretch of open water across which the acting wind has come. The larger storms usually determine the resultant direction of transportation. Now, in the case of the Bay of Quinte, the steep sides of the valley in which the waters of the bay lie so guides and controls the winds

that we find that the efficient wave and wave-current work in shore transportation is done by those winds whose direction conforms nearly with the axial direction of the several sections of the bay. The narrowness of the bay, coupled with the depth of the valley, is such that even violent storms blowing across it can do less efficient work than is done by the much gentler local breezes blowing up or down the bay.

In this locality the prevailing direction of the wind during the summer is from the southwest; but, in spite of this, it is found that, because of the considerations to be noted below, there is virtually no continuous transportation eastward except along parts of the lower portion below the Upper Gap. There seems rather to be a constant oscillation to and fro. Because of the shape of the bay and its position the directions from which efficient winds and their accompanying waves can come are the northeast and the southwest.

The material which forms the forelands varies from fine sand in one example to large rock plates weighing over four pounds each. All the spits but one are built of coarse and fine gravel or shingle. In most cases the material is almost all so coarse that its transportation must be attributed to the wave itself, rather than to the action of any longshore current during the intervals that the wave may have raised it off the bottom, though no doubt these currents assist in that transportation to a small extent. It is moved in part by rolling along the bottom, but even some of the largest fragments are frequently lifted clear of the bottom and carried along with the wave. The shape of the oblong or rhomboidal plates (rarely over an inch thick, and with an area on the flat side, varying from ten to thirty square inches) materially facilitates this mode of transportation.

THE FORELANDS AND BARS.

1. *Sand spit below Bogart's dock.*—This is a small spit which consists wholly of fine sands derived from the adjacent cliff cut in modified drift. The spit measures about 245 feet across the base and extends about 100 feet out from the shore line. The normal width of the beach between the cliff front and the water

is about ten feet. In its present attitude the axis of the spit inclines toward the southwest or slightly down the bay. A reference to the accompanying sketch plan will show the present existing conditions. There is a central triangular terrace at water level, marshy, but filling with sand which drifts in or is washed in by rains or waves. Bordering this are two distinct sand ridges rising about 2 feet above water-level. The outer ridge has imponded a small amount of water between itself and the inner ridge. A third ridge has been begun on the outside of these two.

Referring to the general map, it will be seen that effective

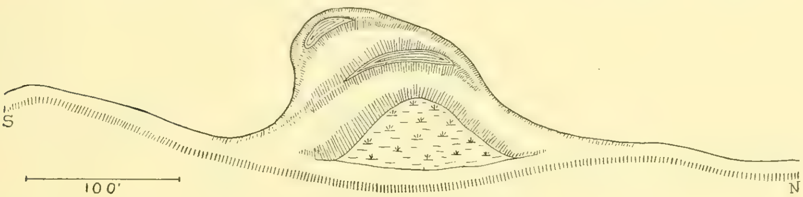

FIG. 2.—Small sand spit below Bogart's dock, June 1, 1903.

transportation must always be by winds blowing nearly parallel to the axis of the middle section of the bay. The present shore line, both above and below, is certainly just as irregular as it is here—it would be described as slightly wavy. There is no stream discharging near here, and there is no evidence of a local landslip having modified the shore line in such a way as to cause the beginning of the building of the spit at this point. In the field it was at first very difficult to see in this case why it should have happened to be formed here and not at a half-dozen other apparently similar places. It happens, however, that there is a very slight, though noticeable, difference in the curvature of the shore line at this place, and it seems as if, under certain special conditions of wind-action from the east of north, the longshore wave and wave currents first started to build a terrace and later a bar outward from the slight salient in the shore line of this point, and that the *same* waves gradually turned the end of this free bar as it reached deeper water, giving it its curved form, and finally tying it on to the shore again. This bar was subsequently

modified and its curves readjusted by waves coming up the bay. At a later period the second bar was built outside the first, under a similar succession of conditions, the waves most actively concerned in its construction coming from the southwest. The third portion was in part built during the summer of 1903, under the action of a series of storms from the northeast. During the process of its building the waves cut into the earlier bars on the north side, producing the concave curve in the shore line at this point, and depositing the eroded material nearer the apex of the spit on the far side of the axis of the initial form, producing the asymmetrical form shown in the plan. If their action continued long enough under the conditions existing at the time the observations were made, the bars would be extended in a very much larger loop and would inclose a very much larger lagoon. The rounding of the end of the spit and the shaping of the convex and concave curves on the south side were actually done by the same set of waves which brought the material to form the outer cap of the spit. In this, as in several other cases, even where the material was coarse gravel, the apex of the spit lies so far off-shore that waves curving obliquely toward it from either direction will only have their shoreward ends retarded as they advance obliquely on the shore. The off-shore portions advance in the deeper water virtually unretarded, and thus the wave front is rapidly curved around the end of the spit. Material moved along a side of the spit toward the end, when discharged at the apex, will often be carried around the end by the more vigorous unretarded portion of the same or the next following wave to that which accomplished its final discharge at the point.

This sand spit seems to be rather an evanescent than a permanent feature of the shore. The present spit is, from the character and size of the sedges growing in the lagoon area, inferred to be several years old, probably not more than five.

2. *Grand bars on Picton Bay.*—On the west side of Picton Bay, nearly opposite the west end of the third section of the Bay of Quinte, are two peculiar bars forming two distinct loops, convex outward, joining the shore by two short concave curves of adjust-

ment. The beach between the cliff-foot and the water is here quite narrow, usually less than 6 feet in width. Above and below the two-loop bars in question the shore line is slightly sinuous, but the beach is of very uniform width. Between the two bars there is a stretch of 78 feet where there is not enough beach gravel to cover the bed-rock, and the cliff rises directly from the

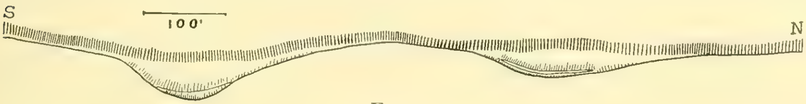

FIG. 3.

water, here about a foot in depth at the shore line. The south loop is 229 feet in length, and the north one 280 feet. The north loop holds a long, narrow little pond between it and the old shore. The low area between the south bar and the old shore was above present water level, and was nearly filled with gravel.

The sudden departure from the normal conditions along this shore to form these bars is difficult of explanation. In the pres-

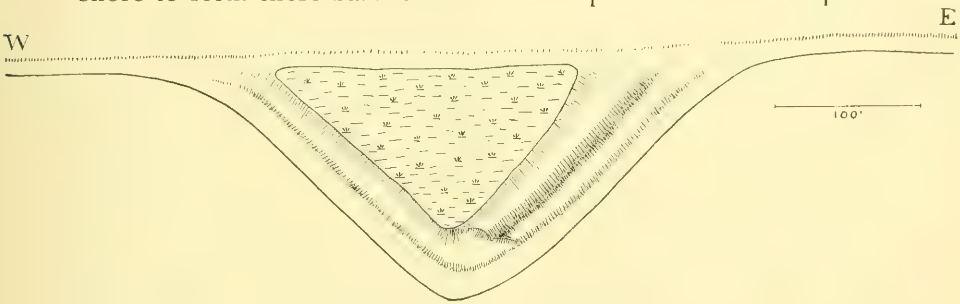

FIG. 4.—Foreland near Allison's dock, May 22, 1903.

ent instance it is possible that a small landslip from the cliff may have temporarily changed the shore line in such a way as to necessitate readjustment by the waves. On the other hand, they may have been formed under the action of the waves alone on the normal shore line, under conditions referred to below in a general discussion of the origin of the forms here described. In this latter case they represent initial stages of a form which reaches its perfection in the V terrace and V bar.

3. *Terrace and bar near Allison's wharf.*—On the north shore of the eastern section of the bay at Allison's dock, there is a sea-

cliff 25 feet in height, cut in till. To the east the cliff becomes much lower. About half a mile east of the wharf occurs one of the most perfect examples of the V-bars. The sea-cliff of till here has a height a little under 5 feet. There is a narrow beach about 20 feet in width. The front of the cliff behind the foreland is more subdued than elsewhere; it is graded, and is covered with sod. The bars which inclose a triangular lagoon are built of gravel and sand. The material of the east arm is chiefly a coarse gravel; that of the west is gravel with a much larger percentage of finer material and some sand. On the inner side there is a small amount of clayey soil which has gradually been blown or washed into the lagoon. The bars are of at least three periods of formation. The oldest rises 3.2 feet above water level the next oldest 4 feet, and the present one about 3 feet. The older beaches have been in part cut off by the newer, as shown in the plan.

The inclosed lagoon is triangular in outline, with rounded corners. The base on the old shore measures about 210 feet, the apical distance along the axis is about 135 feet. The depth of water is about 18 inches. It is more or less grown over with water plants and grasses. The east arm of the triangle measures 144 feet; the west, 165. The apex of the spit is rounded and the nearly straight sides join the shores with short concave curves of adjustment. The east arm of the bar is much higher and wider than the west arm, and its outer end has several times been truncated by stronger storms from the east. The present form of the spit is thought to be due to the activity of the waves, chiefly from the east. The western arm has been straightened and smoothed off at frequent intervals by the less violent, but more constant waves from the southwest. The bottom on which the terrace rests here slopes rapidly downward under the bay, the 100-foot contour lying less than a quarter of a mile off shore.

A reference to the general map shows that this spit is located very near one of the most salient points of the north shore of this section of the bay. On the ground its actual location is about a quarter of a mile to the east of this point, and hence it is sheltered by the point from the storms which blow directly

down the bay from the southwest. Waves which travel up the bay from the east would apparently have their maximum effect on the beach at this point. A little farther east there is another minor point, too small to show on the plan. Beyond this toward the large point (a drumlin) shown on the plan, about a mile and a quarter east of Allison's wharf, the shore débris is very much coarser. Both to the west and east the rawness of the shore cliffs and the coarser beach débris show that there is much more active erosion going on there than in the immediate vicinity of the

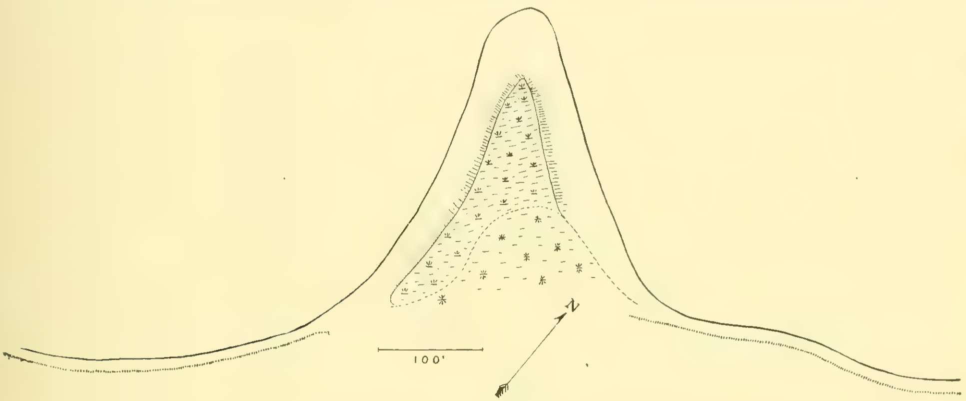

FIG. 5.—Foreland about half a mile west of Prinyer Cove, June 1, 1903.

spit. The inference there seems to be that just at this locality we have a region of relatively quiet water and less activity, where material eroded by the waves acting alternately at different intervals tends to accumulate.

4. *Prinyer Cove spit.*—About a mile west of Prinyer Cove there is a slight salient on the shore line which is tipped by a small V terrace and rimming bars inclosing a triangular lagoon. The axis of the spit lies nearly at right angles to the trend of the shore line. The spit is 275 feet in length and measures about 300 feet across the base. The sides are nearly symmetrical, and the inclosing bars are built of gravel. The inclosed lagoon is in part filled up with rank marsh vegetation; near the edges are some large trees. The apex of the spit shows the lines of successive additions on alternate sides. Inside the present beach only one of the earlier beaches is well preserved. This has been in part

cut into during the readjustment of curves when the present beach was built. The land behind the shore is overlaid by a thin sheet of till. It slopes gently bayward, and the inner margin of the lagoon gradually merges into the mainland. Both on the east and west there is a low cliff above the beach having a height of about 2 feet. The cliff and beach that must have existed behind the lagoon have long since disappeared. The gravel bars on the sides rise about 3 feet above water level. That on the east is a little larger, and consists of coarser material than the one on the west. Almost all the gravel composing the bars is derived from the adjacent bed-rock—a nodular shaly limestone of Trenton age.

5. *Pleasant Point spit.*—This is the largest and the most interesting of all the forelands on the bay. The general form of the foreland is shown by the accompanying plan. The material of which it is built is almost wholly gravel. The eastern side consists of very coarse shingle containing numerous flat plates of all sizes up to three or four pounds in weight. The west arm, on the other hand, consists chiefly of smaller rounded pebbles, rarely over an inch in diameter, and there is also a certain amount of fine gravel and sand.

To the west of the foreland there is a shore cliff about 20 feet in height, of which at least the upper 5 feet are glacial till. The base of the cliff is shaly limestone, and the width of the normal beach is between 6 and 10 feet. It is strewn with coarse cobbles, there being very little fine material such as is found on the arm of the spit a few yards away. The old cliff runs behind the spit; twice it changes its direction, recording significant changes in the growth of the spit. Its height at the base of the eastern arm is only about 5 feet. It continues as a low bluff for some distance to the southeast. The drift varies in thickness, but near the spit its thickness is about 2 feet.

The original foreland so far as it can be traced, lay a little farther to the west than the present one, and was very similar in shape and size to that near Prinyer Cove. At the present time there are seven distinct beaches. Counting east from the inner triangular lagoon, the first three of the beach mounds or ridges each

rise only about a foot above present water level. They are nearly parallel, and between them we find two long, narrow ponds. The fourth beach, the largest and highest of the series, extends nearly the whole length of the spit. The next two are also of considerable height and breadth, and are best preserved near the outer end. In the readjustment of the curves during the formation of

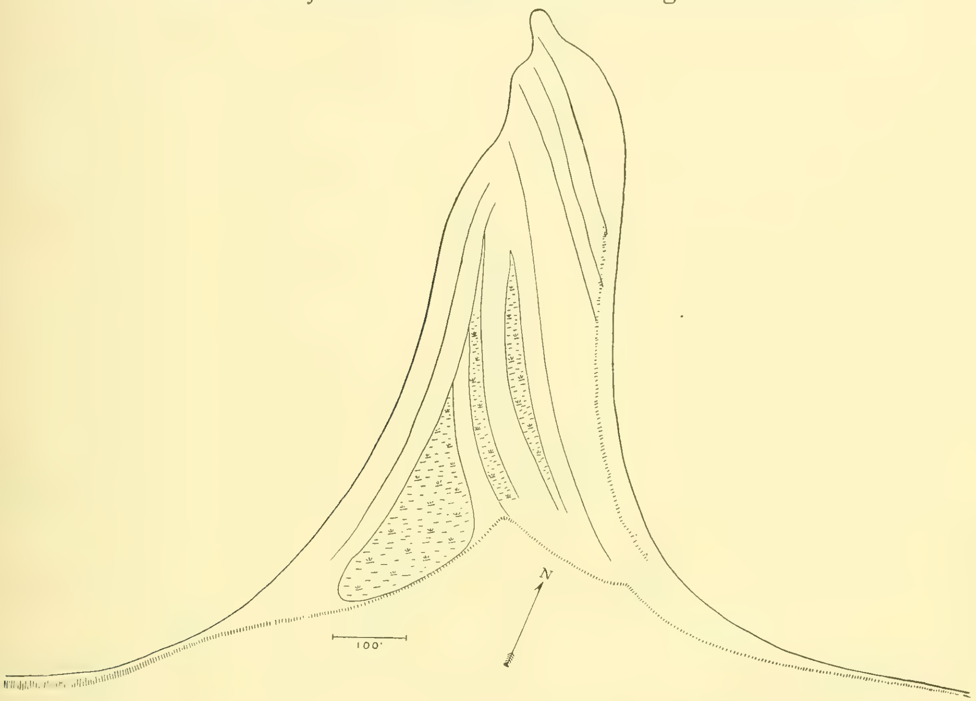

FIG. 6.—Sketch plan of Pleasant Point Foreland, May 23, 1903.

the seventh or modern beach the waves have cut through the sixth and fifth, and are now acting on the fourth near its shore end. On the west side traces of only one ancient beach could be found between the present modern beach and the triangular lagoon. It is assumed, in the counting, that this is the correlative of some one or more of the first six of the earlier beaches found on the east side. Both the beaches on the west side cut across the ends of the first three of the earlier beaches, and the modern one cuts across the ends of the other three as well. The fourth beach on the east, the highest and broadest of the series, rises

about 6 feet above present water level, or at least 8 feet above the bottom of the lagoon. The beach on the west is only about 2 feet high, except near the apex of the spit.

A reference to the general map will show that immediately to the east of the point we have a gap—the Upper Gap—in the side of the Bay of Quinte valley, through which storm waves from the open lake can have access to the bay. The waves which will have most effect on the shore are those coming from a little to the east of south, although the waves of a storm from the east or south will also be capable of effective work. On the other hand, the spit is exposed on the west only to waves traveling up the bay before a wind having a very limited distance in which to act. Hence we find that the larger waves from the open lake have been steadily carrying material around the point, and depositing it in the slack, but very deep, water behind. The point of the spit is now out as far as the 70-foot contour. The much larger size of these waves has been the important factor in determining the coarseness of the material of the eastern part of the spit, in piling it so high, in determining the amount which has been brought here, and in causing the spit to travel slowly eastward. The material which forms the west arm is in part derived from that brought by the bigger waves to the east side and subsequently carried around the point, partly by the same system of waves which brought it, but chiefly by the waves coming up the bay from the northeast at other times. Some of it is brought from the shores to the west. One record of the changes which take place at the apex of the beach under the action of

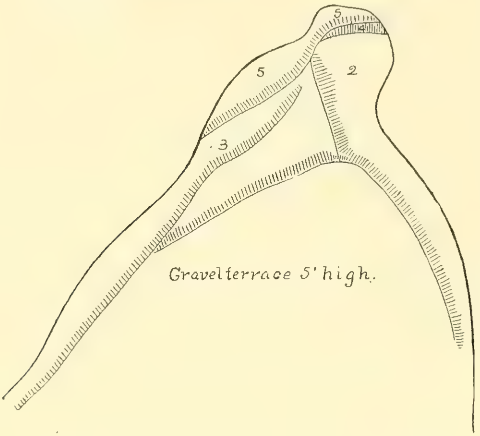

FIG. 7.—Sketch plan of about 100 feet of the apex of the Pleasant Point spit, May 23, 1903, showing the shifting beach ridges and terraces.

different storms is shown in the accompanying sketch. Material is transported very rapidly along the eastern side of the beach, in spite of its coarseness. Along the west the travel seems to be much slower because of the relatively small size of the waves.

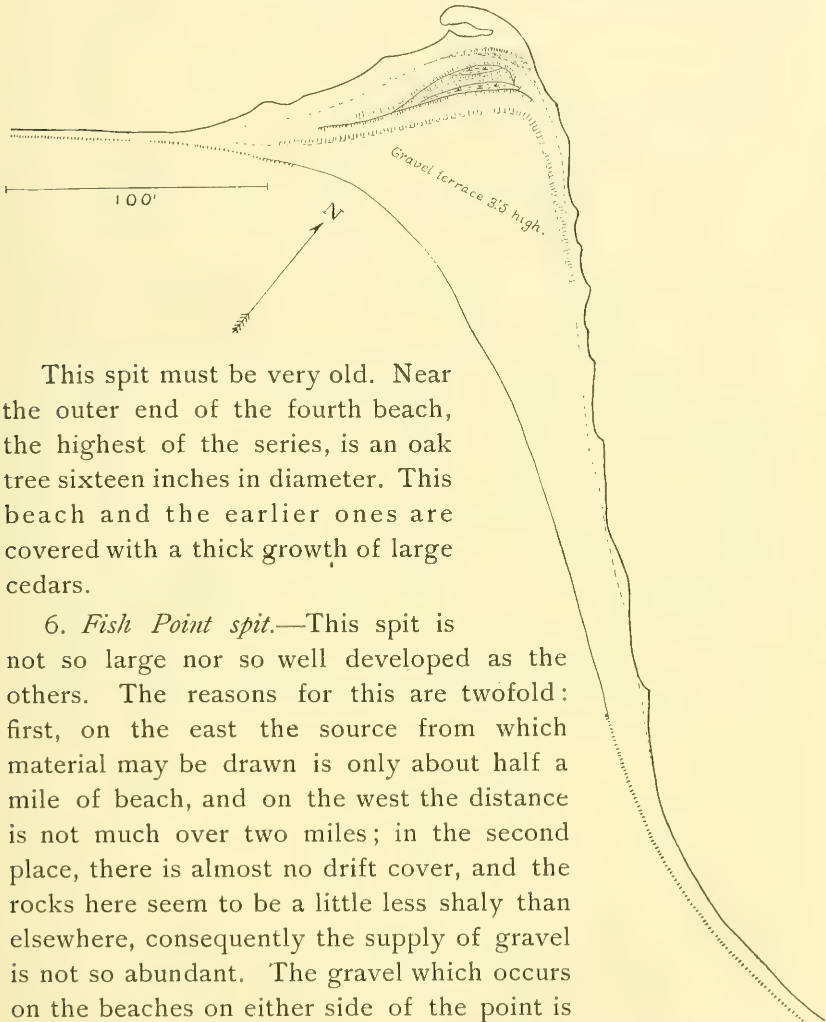

FIG. 8.—Fish Point Foreland, May 24, 1903.

This spit must be very old. Near the outer end of the fourth beach, the highest of the series, is an oak tree sixteen inches in diameter. This beach and the earlier ones are covered with a thick growth of large cedars.

6. *Fish Point spit.*—This spit is not so large nor so well developed as the others. The reasons for this are twofold: first, on the east the source from which material may be drawn is only about half a mile of beach, and on the west the distance is not much over two miles; in the second place, there is almost no drift cover, and the rocks here seem to be a little less shaly than elsewhere, consequently the supply of gravel is not so abundant. The gravel which occurs on the beaches on either side of the point is very coarse, many of the rounded pebbles exceeding two inches in the longest diameter, and there are numerous large plates up to ten pounds in weight. The gravel at the spit is smaller than elsewhere, that on the east

side probably a little coarser than that on the west. The spit, as a whole, resembles a cap which has been built by the gravels on the end of a minor salient of the mainland by the waves when readjusting the shore curves. The main portion of the spit consists of a large irregular or wavy topped terrace of coarse gravel, built out in front of the mainland. For the most part the earlier beaches have lost their individual identity. At the outer margin several of the later ones are still persistent, inclosing shallow lagoons.

The spit was particularly interesting as it exhibited several features, which are described in detail because it is thought that their mode of formation is an index of the way in which the large V bars and V terraces were built up. The eastern side of the spit at the water line had a serrate margin, there being ten distinct, well-marked minor cusps, which for convenience in description may be called cusplets. Each of these had a long, gently curving shore line on the side toward the advancing waves. The free end of the cusplet was joined to the main shore by a short, abrupt, concave curve. Sometimes the free end of the cusplet was drawn out into a sharp, well-developed point. The best-formed cusplets had a sharp median ridge extending down the axis, and often prolonged as an apical spine at the free end. The outer slope, toward the water, was very steep, at first almost a straight line, and then gradually curving around to the normal subaqueous beach curve. The inner slope was much flatter. The curve of the shore line of the individual cusplets was approximately adjusted to the curve of advance of the front of the waves which were building and shaping them (see Fig. 9). The finer gravel lay on the longer back slopes, the coarser fragments, often small plates rather than rounded pebbles, were concentrated on the steeper frontal slopes.

These serrations on the side of the spit seem to owe their origin to the attempt of the waves of a particular series of storms, coming from a nearly constant direction, to readjust the curvature of the shore line to the curvatures of their own fronts. Off shore the waters are very deep, and the shore line of the bay is yet in a very young stage of its development; consequently

the waves traveling obliquely toward the shore are not symmetrically and systematically retarded. The wave does not advance on the shore parallel to its front but comes up obliquely (see Fig. 9). The result is that the gravel was moved obliquely up the slope of the beach, and then obliquely downward with the return of the wave, but always with a resultant in a direction

FIG. 9.—Showing the relation of the wave-fronts to the serrate margin of the east side of Fish Point Foreland.

parallel to the shore. During the period of observation the débris moved along the long curve of the cusplets very rapidly, and then, when discharged into the deepest water at the free end, would either fall at once to the bottom, or might happen to reach the end just in time to be carried across the intervening space by the rush of the less retarded part of the wave which had not yet reached shore. Material would thus be rolled along the long slope by the breaking edge of the wave, but, when discharged at the free end, it was often bodily carried several feet past the

spine of the cusplet and up to the main beach by the more powerful, less retarded portion of the waves—there to be rolled slowly or rapidly along the long slope of the next cusplet, where the process was repeated.

The size of the cusplet in some cases seemed to be increasing, but several seemed to have reached a maximum stage. Given a constant material, the limit of size seems to depend upon the size of the waves and their periodicity.

These little cusps are formed during the period of a single storm, or series of storms, when the waves advance in an oblique direction on a previously evenly curved shore. Their formation and their symmetrical arrangement seem to be due to two factors. In the first place, very frequently the undertow is able to carry material down the slope of the beach a little farther than the front of the wave can move it up, within certain limits. Consequently, although some of the material moved up the slope by the front of the wave lodges, some of it moves down with the undertow, and a small percentage of this latter material may move out beyond the zone at which the next oncoming waves can move it up the beach. Hence there will be a slow but gradual accumulation just beyond this line, which in time will even modify the direction of the long shore currents. A second and more important factor in the production of these serrations along the shore is the development of nodal lines along which material tends to accumulate. Where the waves are advancing at an angle to the shore there will be a number of waves breaking at the same time at different points along the shore. As the spacing of the waves is nearly uniform, if the shore line were perfectly straight, these points of simultaneous wave-breaking would be equidistant from one another. On a curved shore the spacing will be systematic, but the distances between breaking points will not necessarily be equal. Now, the undertow which flows out from one wave as it breaks will interfere with the advance of the next following wave, if it meets that wave on that part of the shore where the orbital motion is nearly a straight line up the beach. This happens very frequently where part of a wave is retarded by a cusplet while the other

part passes the free end with little retardation. The result will be a tendency for the material moving down the slope with the undertow, and up the slope with the advancing wave, to be dropped at a symmetrically arranged series of points. The obliquely moving waves also move débris along the shore in the resultant longshore direction of the wave advance.

The result of the combined action of these different factors is that gradually a little bar is built out from the shore by which the waves attempt to readjust the curvature of the shore line to a curvature appropriate to their direction of advance. Because of the nearly uniform spacing of the waves, these bars will begin at a number of symmetrically arranged points. Because of the normal, uniform slope of the subaqueous floor, the maximum distance from shore at which the undertow can materially interfere with the advance of the next wave will be located at a nearly uniform distance off the initial shore line, and this will tend to limit the size of the individual cusplets. The size is also limited by the distance between the crests of the waves. The building of the cusplets further modifies the form of the shore line, the slope of the bottom, the direction of the advance of the waves, and the direction of the longshore currents; but with waves of constant size an equilibrium will be established, at which time the cusplets will have their maximum size. If the waves are irregular, cusps may not be formed at all.

The same waves which had built the serrate margin along the eastern side of this foreland had built a small flying spit at the apex. Between the free end of this small flying spit and the main beach a very small Λ-shaped point was also gradually built up. The waves coming from the east in the direction indicated by the arrows (Fig. 10) swung around the point, giving it the form shown in the figure. The fronts of the waves assumed the form of a series of helicoidal curves as they swung around the point as if on a pivot. As many as eight waves could be counted swirling around the west end of the flying spit at the same time, the moving crests looking not unlike the spokes of a gigantic horizontally rotating wheel. The relative positions of the successive wave-fronts are shown by the dotted lines in the figure.

Material which had rounded the extreme tip of the flying spit was actually carried across the narrow water space between the flying spit and the little conical point being deposited on the outside of

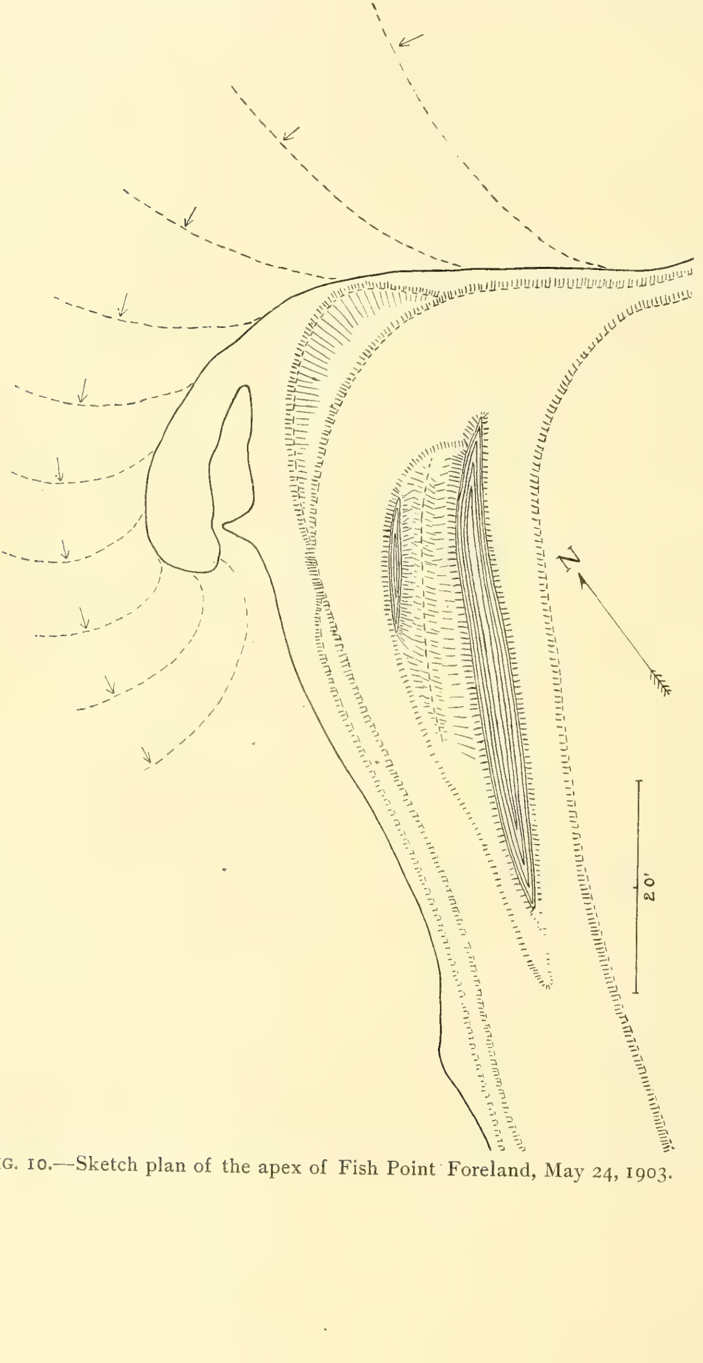

FIG. 10.—Sketch plan of the apex of Fish Point Foreland, May 24, 1903.

the cone. As each wave came in, the water in the small lagoon rose and fell. The outflowing current seemed to be the control which shaped the inner curves of the cone. A little farther to the west the same waves were increasing the size, rounding the ends, and otherwise modifying the two larger cusplets (Fig. 11), which,

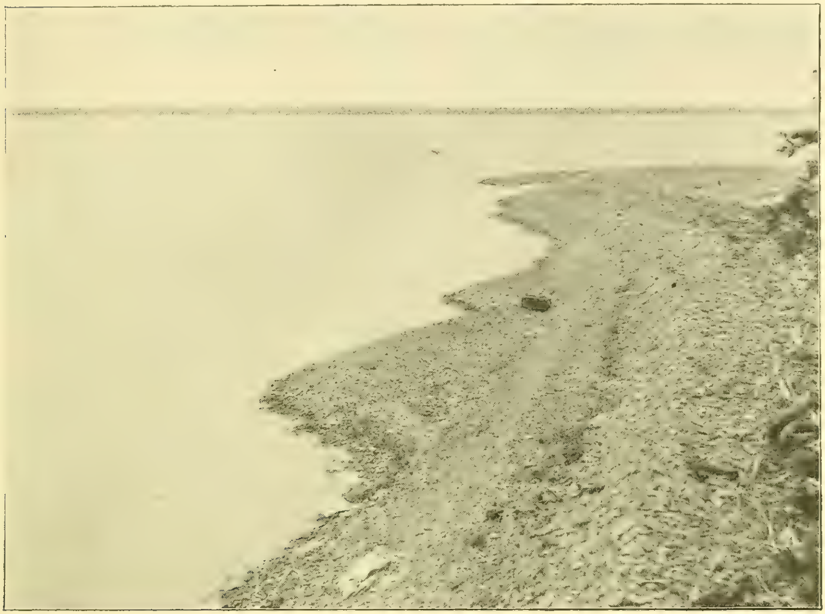

FIG. 11.—Two well developed cusplets in the foreground, the apex of the small loop spit appears in the background. North side of Fish Point Foreland.

judging from their initial forms, had evidently been built some time before by a storm blowing from the west.

7. *Amherst bar.*—Waves rolling into the bay through the lower gap from Lake Ontario have built a long gravel bar off the east end of Amherst Island. This bar runs nearly north from the end of the island and is nearly two miles in length. Most of it is submerged, but near the island a portion rises as a sharp ridge several feet above water level. The eastern end of Amherst Island is low, and the shore is rocky. Most of the gravel forming the bar has been moved along the south shore of

the island by southwest storms off Lake Ontario. The portion of the bar that is above water level has a peculiar curved form, due to the many complex modifications which such a bar may undergo under the influence of minor storms. Some of these are well shown near the free end of that portion of the bar which rises above water level. On the south side of the free end we find two large, well-developed, south-pointing cusps, bounded by curves which are concave lakeward. These cusps seem to owe this form to the action of waves advancing from the southeast and the southwest at different times.

8. *Calf Island loop bar.*—Although not in any way associated with the Bay of Quinte, it seems desirable to include in these descriptions a reference to the loop bar off the east end of Calf Island. The island lies about four miles northwest of Stony Point, and half a mile to the west of Stony Island. Storm waves blowing down the lake naturally divide at the island and pass on either side of it. Coarse gravel derived from the limestone rock, by which the main island is underlaid, has been piled in two high ridges, one leading off from either side of the island. The two unite in a rather sharp point about 350 yards from the east end of the rocky part of the island. The crests of the bars are about 9 feet above water level, and between them is a deep, narrow pond. The south bar is about 60 feet wide, and has equal slopes on either side; the north bar is a little wider and more irregular.

Similar forms are to be looked for off the northeast ends of several of the other rocky islands in this part of the lake. Off the east end of Grenadier Island two long flying spits have formed, inclosing between them a shallow bay known as Basin Harbor. This bay is gradually filling up. The free ends of the two spits are curving toward each other, and, given time enough, we would expect them to unite. In the meantime, the inclosed basin will be partly filled by sand either washed in by the waves or blown in from the bars. The outer slope of the bars will still have the steep gradients of such forms; their height will depend upon the depth of the adjacent water. In time there will thus be formed off Grenadier Island a huge terrace, with running

bars, which in form will approximate in shape to the typical V-terrace and V-bar.

THE ORIGIN OF THE V-TERRACE AND V-BAR.

Four of the forms which have been described in the preceding paragraphs agree very closely, both in form and location, with Gilbert's description of the type examples in Lake Bonneville.[1]

In his descriptions of the type examples Gilbert notes that:

They are built against coasts of even outline, usually but not always, upon slight salients, and they occur most frequently in the long narrow arms of old lakes.

In discussing the origin of the form he states :

In some cases the two margins appear to have been determined by currents approaching the terrace (doubtless at different times) from opposite directions ; and then the terrace margins are concave outward, and their confluence is prolonged in a more or less irregular point. In most cases, however, the shore drift appears to have been carried by one current from the mainland along one margin of the terrace to the apex, and by another current along the remaining side of the terrace back to the mainland. The contours are then either straight or convex.

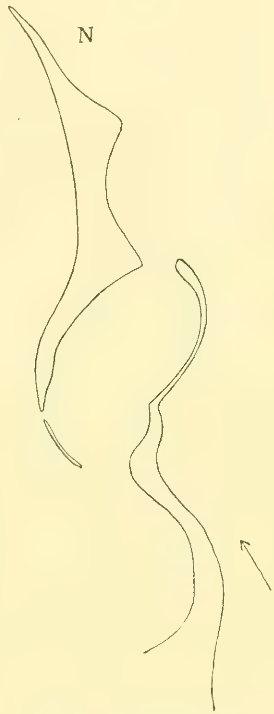

FIG. 12.—Sketch plan of about 500 yards at the apex of the portion of Amherst Bar above water level on May 25, 1903. Direction of wave advance shown by the arrow.

The bars which border the terraces he attributes to a later period during a slight deepening of the waters of the lake, after the terraces had attained their full size. While the lake stood at the higher level, the linear embankments were built at the outer margins.

The author's studies of the forelands in the Bay of Quinte lead him to suggest the following hypothesis as to the mode of origin of the forms here described. In the first place, it must be noted that the level of the water in the bay varies

[1] U. S. Geological Survey, *Fifth Annual Report*, 1883-84, p. 98.

considerably with the seasons, being a little higher in late spring or early summer than at any other time. The level of Lake Ontario also changes considerably during a season. Both of these factors may have some bearing on the formation of the terraces and bars. The changes in level due to the larger seiche waves must occasionally be even greater than these seasonal changes. None of the forms show any evidence which could be interpreted as being due to these seasonal or periodical changes in level.

In a previous paragraph a detailed description was given of the process by which small cusps were produced along a shore. Under the continued action of waves of moderate amplitude the dimensions of these small forms would gradually increase, and eventually they would reach a size which could easily control the shore currents and wave direction of even moderate storms. In the present instance the bay is completely frozen over from about the middle of November until the first of May. During the season of open water the only effective storms are those which chance to be blowing up or down the bay. To be effective, they must have a constant direction, for a considerable interval of time. Hence, while moderate breezes which generate small waves are frequent, violent storms which can modify the work of all previous lighter winds and waves are rare. When they do come, their first work would be to readjust the shore curves developed during the previous interval. The chances that they would preserve a suitable direction long enough to efface the work of the previous, more or less contsant, but less energetic, storms are very slight. The construction of the small triangular terrace may in part be attributed to the leveling action of some such storms as these. In all observed cases, although the terrace under the triangular lagoon had a slight slope outward, its slope was not so great as that of the adjacent shore a little distance on either side of the sand spit; from which it is inferred that there had been some filling. Whether such a process could produce a very much larger terrace than those noted is uncertain. In other cases the portion of the terrace included between the bars may have been partly filled in by the

waves themselves after the formation of the bars. Such a terrace is in course of construction off the east end of Grenadier Island. A similar process is causing a great deal of inconvenience at several harbors along the north shore of Lake Ontario, where two artificially constructed bars in the shape of piers inclose a harbor which periodically fills with sand that has to be removed by dredging.

In some cases the inner lagoon may have been filled after the bars were formed, by ordinary processes of transportation which tend to fill hollows and lessen the grade of steep slopes.

The size of the terrace would also depend upon the size of the water body, and upon the character of the material. The tendency will always be for the waves bringing the supplies of material to heap this up in the form of a bar. In the later stages, when the accumulation has become considerable, the larger storms would not be able to efface these bars, though they will reshape them and pile the material higher on the outer margin. On the outer side of a bar, below water level, the material has a gentle slope to below wave base. Beyond this the inclination of the front slope will be the angle of repose for material of the kind. In the case of all the forms on the Bay of Quinte, where the water drained off it would be found that the forelands would have steep frontal slopes, with an elevation in several cases of about 60 feet. The top would be a nearly flat terrace, with gently curved edges, and rising above it at a little distance from the margin would be the sharply defined rimming bar.

In the smaller examples the same waves which build the one side of the foreland carry material around the end of the spit and distribute it for a shorter or longer distance, according to their size, on the other side. On some occasions the same waves may shape both sides at the same time, but usually it is found that the adjacent sides are shaped alternately. In some cases the greater proportion of the material comes from one side, and its redistribution on the opposite side of the spit is effected by other waves from a different direction and at another time. In the case of Point Pleasant spit it seems to be slowly shifting eastward, as material brought from the southeast accumulates on

that side. At the same time less rapid erosion is taking place on the west side under the action of less violent waves.

CONCLUSIONS.

In conclusion, it may be stated that the forelands here described seem to have been built wholly by the action of waves acting either directly or indirectly in association with longshore currents which were intimately associated with them.

The location of the forelands is associated with some more or less salient feature of the coast which has influenced the direction of wave advance and the course of longshore currents, and has localized the effective transporting action of both.

Their formation is due to the control exercised on wind direction and on wave direction by the form of the bay. The form of the forelands is due to the peculiar character of the long, narrow water body on which they are situated, the conditions being such that only certain classes of storms can be effective agents in the shore transportation. The immature character, and consequent imperfect adjustments of sub-acqueous portions of the shore is an important control in wave-work.

The V-terrace and the associated V-bar upon it, in the instances here studied, are regarded as products of the same agent, and do not necessarily imply a change in water level. The evidence from Point Pleasant spit implies that there has been no significant change in level during the long period of growth of the greater part of the spit.

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A CONTRIBUTION TO THE STUDY OF THE INTER-GLACIAL GORGE PROBLEM.[1]

Topography of the Finger Lake region.—The topography of the Finger Lake region is too well known to American geologists to require any detailed description here. The rocks, which are almost wholly Devonian, consist of great deposits of shale and sandstone, with a few thin beds of limestone. These rocks have never been greatly disturbed and lie nearly horizontal, with a slight southward dip. In the Cayuga Lake district there is a series of gentle folds which cross the lake valley in the east-west direction. A glance at the even sky-line presented by the hill-tops shows that the region is a great plateau. This plateau has been so deeply dissected that it resembles a mountainous country, with the hills often rising several hundred feet above the valley bottoms. About fifteen miles south of the heads of the lakes is a dissected divide that Professor Tarr[2] has characterized as being "high and diverse in topography." From the divide the plateau slopes northward and merges into a drift-filled region at the northern ends of the lakes. Here, doubtless, there was an escarpment in preglacial times, but it is now nearly obscured by drift.

Cayuga Lake valley.—From the divide at Spencer Summit the valley of Lake Cayuga extends northward a distance of nearly fifty miles, when it is lost beneath the drift. Professor Tarr[3] has called the divide at Spencer Summit a divide of "destructional origin." He considers the depth of the drift here to be slight; and from the steepness of the walls he infers that the divide must have been higher in preglacial times, "having been lowered

[1]This paper was originally written as a thesis for the master's degree at Cornell University. Since the preparation of the original manuscript enough new information has been secured to warrant a slight revision, and therefore some changes have been made. The writer is indebted to Professor R. S. Tarr for many valuable suggestions concerning the field investigations and the preparation of the original paper.

[2]R. S. TARR, *Bulletin No. 5*, Geological Society of America, p. 340.

[3]*Ibid.*, p. 341.

by glacial erosion." There is also good reason for believing that the divide has been lowered by stream erosion. The ice in its advance would close the outlet of the lake valley, causing a lake to be formed between the ice front and the divide. The drainage of this lake across the divide would continue until the ice had advanced to the divide. In receding the ice would again cause the formation of a lake in the valley, which would exist from the time the divide was uncovered until the ice retreated far enough to uncover a lower outlet. The drainage across the divide would naturally tend to lower it. The amount of erosion would vary with the length of the time. The presence in Cayuga Valley of the well-developed terminal moraine of the Wisconsin glacial epoch points to the existence of an ice-dam in the valley for a long time. This fact points to the probability of the divide having been considerably lowered by stream erosion. The effect of the drainage across the divide would be influenced by the relative altitude of the northward- and southward-flowing streams. If the southward-flowing streams had cut considerably below the level of those flowing northward, the water would fall into the deeper valleys, and the divide might be destroyed in a very short time by the recession of this waterfall. If, as seems more probable, the northward-flowing streams had reached the lower level, the removal of the divide would be much slower. On this point Professor T. L. Watson has said:

> It can hardly be doubted that the Laurentian tributaries were the stronger streams, therefore encroaching upon the territory of the other system, and thereby causing the southward migration of the divide.[1]

We should also bear in mind that there is a possibility of a differential uplift having rejuvenated the Laurentian streams just before the glacial period. Mr. M. L. Fuller[2] failed to find evidence of this uplift in the area covered by the "Elkland-Tioga Folio":

> It has been frequently urged among geologists that the advent of the earliest Pleistocene ice-sheet was preceded by a general uplift of the northern half of the continent, affecting the surface throughout the northern por-

[1] "Some Higher Levels in the Post Glacial Development of the Finger Lakes," *Report*, N. Y. State Museum, Vol. I (1897), p. R. 68.

[2] M. L. FULLER, "Elkland-Tioga Folio," U. S. Geological Survey, p. 7.

tion of the United States. In western Pennsylvania, however, the presence of Pleistocene river gravels on rock terraces several hundred feet above the bottom of the present gorge of the upper Allegheny River indicates that the last stage of the active erosion did not begin there until after the first ice invasion, though the uplift and the inauguration of the erosion in the lower reaches of the river may have been somewhat earlier. The uplift recorded by the rock terraces immediately adjacent to the Susquehanna in the eastern portion of the state is of questionable date, but would appear to be of late Tertiary or early Pleistocene age.

In the Elkland-Tioga region there appears to be a slight notching in the bottom of the old valley of Pine Creek and some of its tributaries, but it is believed that this was not produced until after the southward deflection of the lower portion of the creek through the gorge south of Ansonia. This diversion, as will be described more fully in the discussion of the earliest glacial stage, was probably due in great measure to the accumulation and overflow of waters ponded in front of the advancing ice-sheet, and the consequent reduction of the divides and the cutting of a new channel in which the stream persisted even after the ice had disappeared. The notching of the bottom of Pine Valley and its branches was a result of the diversion through the new and lower channel, and affords no evidence of uplift.

The Elkland-Tioga region is not far from the Finger Lake region. It is, however, on the south side of the divide, and includes some of the streams which are tributary to the headwaters of the Susquehanna River. If rejuvenation had effected the Laurentian drainage, this would tend to increase rather than diminish the advantage of the northward-flowing streams over those flowing southward.

The hills, which rise steeply at the southern end of the lake valley, become lower and more gently sloping as you pass northward. The valley also widens rapidly toward the north. While a mature stream valley ought to become wider and the walls more rounded toward the mouth of the stream, the change here is so rapid as to suggest that there must be some other explanation to account for a part of the difference. One cause which has probably contributed to this end is the northward differential depression which occurred at the close of the glacial period. If this depression amounted to no more that two feet per mile, it would have made a difference of one hundred feet in the relative height of the land at the ends of Cayuga Valley. It has been suggested that the difference in the topography at the

two ends of Cayuga Valley is due to a difference in rock texture.[1] The southern part of Cayuga Valley is cut in the hard, durable Portage sandstone, while farther north are the soft Hamilton shales which break down much more easily when exposed to the agents of weathering. Another point of considerable, though undetermined, importance in this connection is the intense glaciation to which the northern end of the lake valley has been subjected. As suggested by Dr. G. K. Gilbert,[2] the belt in which the northern end of the lake lies has been much more intensely scoured by the ice than the belt south of the lake. The width of the lake varies from about a mile near its southern end to about three miles near Aurora. The surface is 378 feet A. T., and the greatest depth is 432 feet. For considerably more than half its length the bottom of Cayuga Lake is below sea level. The drainage of Cayuga Valley is northward into Lake Ontario.

Direction of preglacial drainage.— While some of the earlier writers believed that the preglacial river which occupied Cayuga Valley flowed southward, all the later students are agreed that it drained northward into the Ontario basin. The hypothesis of a northward preglacial drainage is based on the following lines of evidence: the general northward slope of the land; the wider and more mature aspect of the valley as one passes northward from the divide; the increasing number of tributaries near the divide; and the fact that the bottoms of the mature tributaries become lower from the divide northward. While all these lines of evidence have been affected by the various changes accompanying glaciation, it has not been sufficient to destroy their value as evidence in this connection. Since there are no facts opposed to the theory of a preglacial drainage toward the north, we may regard the hypothesis as established.

Postglacial gorges.— With few exceptions, all the tributary streams which occupy mature preglacial valleys enter the main valley through narrow, rock-walled, postglacial gorges contain-

[1] *New York Geological Survey of the Fourth District* (1843), p. 225; *Monograph XLI*, U. S. Geological Survey, p. 79.

[2] Paper read before the Geological Society of America, December, 1902.

ing many rapids and waterfalls. The length of these postglacial gorges is usually less than three miles; and the amount of fall varies from about 100 feet to over 500 feet per mile. The descent is usually accomplished by means of a series of cascades, though

FIG. 1.—Taghanic Falls.

in a few cases there are cataracts of considerable height. Taghanic[1] Falls, the highest, measures 200 feet. Many of these falls have developed on account of an alteration of hard sandy layers with layers of soft, easily eroded shale. A few cataracts

[1] This spelling is in accordance with that on the Genoa atlas sheet of U. S. Geological Survey.

also occur over the Tully limestone, which caps the soft Hamilton shales. In general, the amount of fall in the postglacial gorges diminishes toward the north, although there are some exceptions to this rule.

The principal cause for this gorge condition, in the lower part of the tributary valleys, is the fact that the streams have been turned from their old channels and forced to cut new ones. Another cause which has contributed to the same end is the widening and deepening of the main valley by glacial erosion. In some cases the streams have possibly been turned aside by a moraine dam, but the most common obstructions are the deltas deposited in the ice-dammed lakes[1] which formed in front of the continental glacier. These lakes fell to successively lower levels when lower outlets were uncovered, and the streams continued to flow along the course occupied when the lakes fell. The new channels are mostly south of the old course, and Professor Tarr[2] has attributed this to the effect of the prevailing north winds on the waters of the extinct lake. Coy Glen, being exposed to the south winds and protected from the north winds, lies north of its old channel.

Interglacial gorges.— In every case where the streams have been turned aside in the manner just described there is a lower course in the same broad valley, which is itself a gorge. Professor Tarr has already called attention to these gorges in his *Physical Geography of New York.*[3]

Interglacial (?) gorges.—In central New York there are numerous gorges which are broader than the postglacial valleys and partially obscured by glacial till, showing that they were formed either during preglacial or interglacial times. This class of valley is especially well illustrated in Six Mile Creek, where its relation to the broad, mature preglacial valley is well shown. In one case, near Taghanic Valley, lake beds containing fresh-water fossils have been found beneath the till.

One naturally thinks of these gorges as being interglacial in

[1] H. L. FAIRCHILD, *Bulletin VI*, Geological Society of America (1895), pp. 353–74; T. L. WATSON, *Report*, New York State Museum (1897), pp. 55–117.

[2] *Physical Geography*, N. Y., p. 177. [3] Pp. 178, 179.

origin, and this explanation seems, at present, the most probable; but all that can now be said with certainty is that they antedate the last advance of the ice. The question of these gorges has a very important bearing upon the whole subject of the drainage history of central and western New York. Were the gorges due to interglacial conditions or to an uplift of preglacial times? Leverett refers to similar gorges in his monograph[1] on *The Glacial Formations and Drainage Features of the Erie and Ohio Basins.*

> The valleys of this hilly country present marked differences in topography. In some valleys the slopes from top to bottom have a mature aspect, while in others the upper part of the slope is mature, but the lower part is gorge-like and youthful in appearance. The phenomena suggests at once that some valleys have remained below the level of stream-cutting, while others have been undergoing a marked trenching. In these which have been deepened, the old valley bottoms are traceable along the brow of the rock gorges or canyon valleys, for the old valleys are generally broader than the new ones. In some cases, however, the new valleys occupy the whole width of the bottoms of the old ones, and there is only the change in the angle of the slope of the valley bluff to mark the depth of the old valley. There is, in some valleys a series of complex terraces or rock shelves, of which one set or system stands at the brow or border of the canyon valley, and the others at higher altitudes. There are also, in some cases, rock shelves inside the trenches of the canyon valleys. The set of trenches standing at the brow of the canyon valley is, however, a far more persistent feature than any of the others, and it is this set which receives chief attention in the ensuing discussion of drainage systems. It seems to mark a true gradation plain, formed when the stream was in condition between degrading and aggrading its bed.

All the preglacial tributaries of Cayuga Lake Valley which have been examined have gorges cut in their bottoms, and these gorges are wider, and in many cases deeper, than the postglacial gorges. The approximate width of the drift-filled gorges can usually be ascertained without much difficulty. On account of the drift-filling, the depth is not readily determined; however, Evans, who studied Taghanic carefully, mapped the old valley bottom as continuous above the level of Lake Cayuga.[2]

Ten Mile Creek.—Ten Mile Creek, despite its name, is only about six miles in length. It rises near the village of Danby and flows a little west of north, entering the Inlet about two miles

[1] *Monograph XLI*, U. S. Geological Survey, p. 80.

[2] R. M. EVANS, Thesis on Taghanic (1897), Map. II.

south of Ithaca. The stream occupies a broad, mature valley with gently sloping sides. This valley divides at Danby, the branches becoming narrower and the walls steeper for some distance beyond the village. While Ten Mile Creek now rises at Danby, there is evidence that the preglacial divide was farther south. Danby Creek, which rises near the east branch of Ten Mile Creek, flows southward through a valley which gradually narrows for a distance of three miles and then widens again. Michigan Creek, which heads near the west branch, flows through a similar valley; but in this case the narrowest part of the valley is only about two miles from the source of the stream. The narrowing of these mature valleys cannot be explained on the ground of rock texture, for the rocks here are of uniform character. The narrowing may be explained by supposing that the narrowest part represents the divide between these streams at the time the broad valleys were being formed. The divide hypothesis is strengthened by the fact that the highest hills are on either side of the narrowest parts of the valleys; and by the additional fact that the present divides are clearly of constructional origin, being composed of low drift ridges. The drift ridges are within the limits of the region covered by the last ice-sheet; and the present location of the divides was determined by the material deposited at the ice-front.[1]

About a mile from the Inlet, Ten Mile Creek enters a narrow postglacial gorge; and in less than a mile it falls, by a series of rapids and cascades, through a vertical distance of about 420 feet. The highest falls are the two cascades near the edge of the inlet, which together measure 190 feet. Running nearly parallel to this gorge is a drift-filled gorge, which is much broader and deeper than the postglacial gorge, as shown by sections 1 and 2. The buried gorge is now occupied by a small stream which has removed the drift down to 520 feet A. T., but has not reached the rock bottom. The width of this gorge is 250 yards; its depth is not known, but the north wall rides 156 feet above the drift which forms the bed of the present stream. The lower end of this stream is through a small postglacial gorge, cut in the north

[1] For location of the divides, see Map I.

wall of the filled gorge. There is a rock terrace[1] on the south side of the buried gorge at 620 feet A. T., which probably represents a former level of the stream, for there is a tributary gorge on the north side near the cemetery which enters the main gorge at about the level of this terrace. The tributary shows as a gap in the wall of the main gorge, just below the cemetery and it is crossed by a small stream just above the cemetery. A short dis-

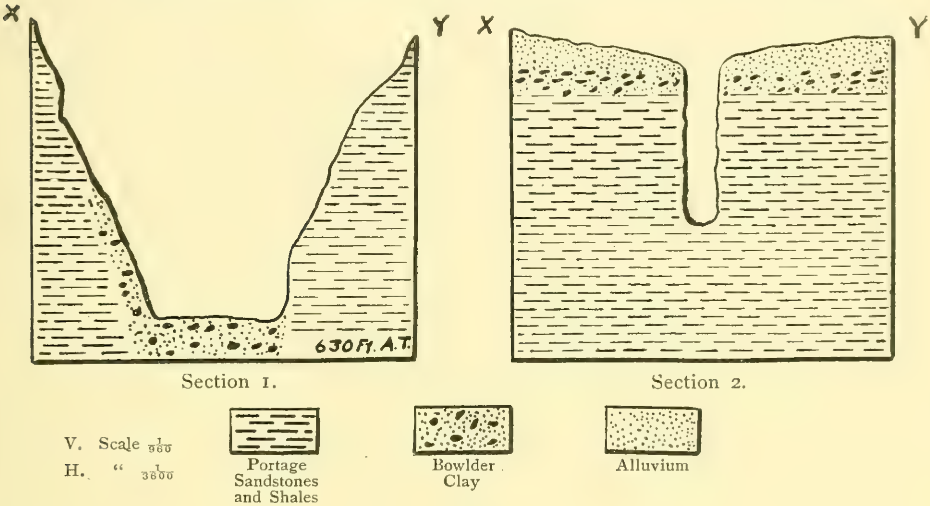

FIG. 2.

tance from the inlet the present stream crosses a small buried gorge, which must have been another tributary, for the rock is practically continuous at 720 feet A. T. between the old gorge and the postglacial gorge.

If we look upstream for the continuation of the large buried gorge, we find that it appears just above the delta which was built by the stream in Glacial Lake Ithaca.[2] Above this delta the gorge can be traced nearly a mile to where it is finally obscured by the drift. In that distance the stream has cut two small postglacial gorges around drift obstructions which block

[1] The writer has begun a study of these rock-shelves which he hopes will lead to an explanation of the direction of flow, and at the same time elucidate some other points. The photograph taken in Six Mile Creek shows two terraces.

[2] T. L. WATSON, *Report*, New York State Museum (1897), pp. r55–r117.

the main gorge. One of these postglacial gorges is shown on Map II.

Map II comprises an area 1,000 yards long, and from 250 to 600 yards wide. The lowest part of the map is at the city reservoir, 880 feet A. T. The contours were mapped on either side of the stream up to 1,000 feet A. T. Above the 1,000-feet contour the surface rises very gently to the divides between Ten Mile Creek and the neighboring streams. There are three ridges on the map which extend nearly east and west, and rise to a height of 100 feet above the stream. Each ridge is composed partly of drift and partly of rock covered with drift.

Channels of Map II.—The stream enters the map through a broad drift floored channel, and, after crossing the rock in the southern ridge through a narrow postglacial gorge, it enters another drift-floored channel, through which it flows to the city reservoir. Below the reservoir the stream flows through the narrow postglacial gorge described earlier in this paper. In addition to the channels now occupied by the stream, there are four other channels within the area of Map II. Two of these channels pass beneath the southern ridge, one east of the present stream (see map, *A*), and one west of the present stream, and just south of the house (see map, *D*). There is a channel beneath the middle ridge west of the rock outcrop (see map, *B*), and one beneath the northern ridge, east of the rock outcrop (see map, *C*).

Evidence of the existence of channels.—The general evidence of the existence of these channels is of two kinds: (1) the trend of the rock outcrops; (2) the existence of well-defined indentations on the upstream side of each of the ridges. These indentations were produced by the stream swinging against the soft drift ridges. The drift was not entirely removed from the channel, because the rock in the ridges prevented the formation of a broad meander within these channels. In the case of the channel (*D*), west of the postglacial gorge, the drift ridge has been so badly eroded that the rock-walls show above it, and near the southern end of this channel the wall has been exposed down to the bottom of the channel (Plate V). The hypothesis of a

channel (A), east of the postglacial gorge, is strengthened by the fact that the channel west of the postglacial gorge is too narrow and too shallow to be the continuation of the broad channel south of the ridge. The existence of a channel (B) beneath

FIG. 3.— Terraces in the drift-filled gorge of Six Mile Creek.

the middle ridge is very apparent in the field; and is fairly well shown by Plate VI. A boring made on the top of the ridge to a depth of ten feet did not strike rock, although the bottom of this hole is more than twenty feet below the highest rock in this ridge. The channel between the middle and north ridges seems rather narrow to be the continuation of the broad channel on the east side of the map, and the well-defined indentation (see Plate

VI and Map II, *C*) on the south side of the north ridge, points strongly toward the existence of a channel beneath the ridge.

Nature and size of channels.—The fact that the rock rises perpendicularly above each of these channels indicates that they are gorges, and the rock in each of the ridges forms a rock island. The postglacial gorge is 25 yards wide, 50 yards long, and 90 feet deep. The gorge south of the southern ridge is over 250 yards wide and 100 feet deep. The drift has been removed down to 910 feet A. T. without exposing the rock bottom. The gorge (*D*) just south of the house is 35 yards wide and 90 feet deep. It has its bottom at 910 feet A. T. This is at the same time level as the bottom of the postglacial gorge. The gorge running east from the house is 125 yards wide and 110 feet deep. Its bottom, as indicated by borings near the house and between the rock in the two ridges, is below 890 feet A. T. The gorge just south of the reservoir is more than 175 yards wide and it has been cut to 880 feet A. T. without encountering rock. This would give it a depth of 120 feet. The gorge between the middle and northern rock islands, is 125 yards wide and has a drift bottom 900 feet A. T. The outcrop along the stream at the east end of this gorge, is an extension of the rock in the northern ridge and it was probably originally at the same height, having been lowered by the swinging of the stream against it. It now stands 905 feet A. T.

The arrangement of the sections of gorges into a series of continuous gorges depends upon size, depth, and position. Gorge No. 1[1] passes beneath the southern ridge, east of the middle ridge, and east of the rock in the northern ridge. From the slope of the rock-floor of the broad valley, as indicated by well records and rock outcrops, this channel must lie approximately in the axis of the broad valley of Ten Mile Creek, already described. Gorge No. 2 passes beneath the southern ridge, westward past the house, beneath the middle ridge, and west of the northern ridge. That this gorge could not pass between the middle and northern ridges is shown by the fact that its bottom

[1] The numbering is for convenience only, and does not indicate the supposed chronological order of formation.

is lower than the low rock outcrop which extends along the eastern edge of this channel. We still have left Gorge No. 3 and Gorge No. 4. These gorges may possibly belong together, though that is by no means certain. By taking the low ridge of rock east of the stream as one edge of Gorge No. 4, we can reduce its width to 75 yards, but it is still nearly three times as

FIG. 4.—A view in the drift-filled gorge of Ten Mile Creek.

wide as Gorge No. 3, and it is also more than 10 feet deeper. If, however, we assume that there was a fall somewhere between the two gorges, it would account for the difference in depth; but this assumption does not explain the difference in width.

Downstream extension of these gorges.—All these gorges must have entered the inlet through the broad gorge below the reservoir, which lies north of the postglacial gorge, for the rock-wall of the Inlet Valley is continuous for two miles on either side of the drift-filled gorge, except where there are postglacial trenches. It is possible that there is a local divergence of the small

drift-filled gorge. The stream which cut this small gorge may have turned aside and entered the broad drift-filled gorge through one of the channels which were mentioned earlier in this paper as being tributary to this gorge.

Origin of the rock islands.—As already shown, there are three rock islands on Map II. In considering the origin of the rock islands, the first question is: Could they have been formed during the normal stream development? A stream abandons its old course and takes a new one when ox-blow lakes are formed; but this happens when the stream is flowing on a flood plain, where the work of cutting across a spur is comparatively easy. In the case which we have to consider the rock is hard enough to offer considerable resistance to stream erosion. Moreover, the shape of the rock island is a serious objection to this theory. If they had been formed by a stream meandering, they should be rounded on the upstream side. Reference to the map will show that all of the rock islands are cut off squarely on the upstream side.

A second way in which rock islands may be formed is by lateral swinging of two streams until they cut through the divide which separates them. If the rock islands had been formed in this way by the uniting of the main stream and a tributary, they should taper to a point on the upstream and downstream sides. None of the rock islands have this form. In the case of the southern rock island, this hypothesis would meet with another objection from the fact that the rock-wall of the old gorge is continuous for one-half mile above the area of Map II.

From what has just been said it seems impossible to attribute the rock islands to normal stream action. Another possible hypothesis is that the rock islands have been formed as a result of glaciation. In this connection, two possibilities arise. Some of these gorges may have been overflow channels of glacial lakes, or the stream may have been forced to cut new channels around glacial deposits which obstructed its former course.

Can any of the gorges be the overflow channel of the glacial lakes? The gorges cannot be the overflow channels of a glacial lake, for there is no place where a lake could form with an outlet at this point. Any lake formed in front of the ice in the

inlet would drain over the divide at Spencer Summit, and the drainage of a small lake in Ten Mile Creek valley would naturally have to pass over the divides, not along the axis of the valley where these channels are located. For this reason, any gorges which would be formed as overflow channels ought to show on the divides, where a careful search has revealed none.

FIG. 5.—Looking down stream. Postglacial gorge of Map No. II on the right. Gorge D on the left.

Could the gorges have been formed interglacially? After glaciation, streams naturally begin to flow along the lowest courses. If the drift deposit is great enough to obscure much of the preglacial topography, the streams may take very different courses from those occupied preglacially; but if the amount of drift-filling is slight, they will naturally follow preglacial drainage lines. There may be partial abandonment of old drainage lines, as in the Genessee River,[1] or the stream may follow

[1] An enumeration of the cases of reversions of drainage which have been described by various writers would be too large an undertaking for the scope of this

approximately its preglacial course. It is possible, then, that these may be interglacial channels, but it would be just as impossible to have them all formed in one interglacial period as to have them all formed during normal stream development.

The hypothesis that some of the gorges were cut because of drift obstructions requires no different conditions from those existing in scores of places near here. Ten Mile Creek has been forced to cut three short postglacial gorges, because of such obstructions. The acceptation of the above hypothesis calls for a greater number of epochs of deglaciation than has heretofore been recognized in this region; but when we consider the great complexity of drift deposits, which has been recognized elsewhere, we do not feel that it is necessarily an objection. This hypothesis has no facts opposed to it, while all the others are open to objections which arise from conditions in the field; therefore we may regard it as established.

Age of the gorges.—A considerable lowering of the divide between the Cayuga River and the northward-flowing streams might have produced a rejuvenation of the streams tributary to Cayuga Valley. There is, however, little doubt that the Laurentian streams were stronger than the Susequehanna; consequently such a rejuvenation at the time of the first glacial invasion is improbable. What may have been the exact conditions governing the erosion at the divide during the remainder of the glacial period is, as yet, unknown.

Ten Mile Creek was a small tributary near the source of the preglacial Cayuga River, and would not feel the effect of an uplift until long after the rejuvenation had begun in the lower reaches of the stream. It is also questionable whether the uplift occurred long enough before the glacial period to permit the rejuvenation of the entire Laurentian drainage before its lower reaches were obstructed by ice. Nevertheless, the possibility of such rejuvenation must not be ignored.

paper. Among the best known and most extensive are those of upper Ohio, described by CHAMBERLAIN AND LEVERETT, *American Journal of Science*, Third Series, Vol. XLVII, No. 280, pp. 247–82. For descriptions of local reversions see *Physical Geography of New York* (1902).

While we cannot eliminate the possibility of a preglacial rejuvenation, we can limit the effect in Ten Mile Creek valley. The bottom of the broad valley in Ten Mile Creek is about 720 feet A. T., and there is a shelf in the drift-filled gorge at 620 feet A. T. A differential uplift increasing at the rate of three feet per mile (which would be a fair estimate) to the northeast might cause trenching to 620 feet A. T. without producing a rejuvenation of the streams of the "Elkland-Tioga Folio." To permit erosion to the lowest known point in this gorge would call for an uplift twice as great, while to reach the lowest known depth of any of

FIG. 6.—A view of the middle ridge looking down stream.

the gorges would require an uplift which would effect the streams south of the divide. Therefore, it seems safe to conclude that the main trenching of the broad valley was interglacial, and that in the case of Ten Mile Creek the preglacial uplift did not cause the stream to cut below 620 feet A. T. There is considerable evidence that the broad valley of Six Mile Creek contains two drift-filled gorges with their bottoms below 540 feet A. T. This fact would seem to indicate at least two periods of deep trenching after the first glacial invasion.

The length of the deglaciation intervals.—In considering the length of the intervals of deglaciation, we are confronted by a great many difficulties. One of the most troublesome points is our lack of knowledge of the depth of the various gorges. Another difficulty, which is almost equally troublesome, is the uncertainty as to their chronological order. From the fact that

the buried gorge (*D*) south of the house has its bottom at 910 feet A. T., while all the others have been excavated to a still greater depth, we may conclude that excavation of the gorges to their greatest known depths would require a large amount of erosion since the glacial period. If all the gorges are interglacial, the ice must at one time have retreated far enough to permit gorges to be cut down to, if not below, the present lake level. This would probably require a northward drainage. A comparison of the relative widths and depths of the various gorges shown on Map II brings out the fact that the amount of erosion required to excavate the buried gorges was considerably greater than the amount accomplished in postglacial times. This subject is complicated by the fact that the drainage basin of Ten Mile Creek has been reduced in postglacial times; but even making a large allowance for this reduction in drainage area, we may safely say that the shortest interval of deglaciation was probably fully as long as the postglacial time, while the others were considerably longer—in at least one case, several times as long,

Cause of the gorge-cutting.—In the formation of the broad valleys the streams must have reached base level. The only thing that could bring about rejuvenation of the streams, resulting in gorge-formation, is an uplift of the land. This uplift must have been of long duration, even though the streams may have found some of their work of degradation, below the old valley floors, accomplished by glacial erosion. The amount of this uplift cannot be determined; but from the fact that the buried gorge of Six Mile Creek has been cleared of drift down to 420 feet A. T., without reaching rock bottom, it follows that the uplift must have been sufficient to permit the stream to cut below that depth. The buried gorge of Butternut Creek, on the west side of the Inlet Valley, is over 250 feet deep; hence the amount of uplift must have been at least 250 feet. Since Butternut Creek is at present flowing 250 feet below the old valley floor, we may also assume that the postglacial altitude is probably fully 250 feet greater than the altitude when the broad valleys were formed.

Summary.—Briefly summarized, this paper is intended to show the existence of a series of complex gorges which are considered interglacial. The minimum number of epochs of deglaciation is two; the maximum number, four. The amount of ice recession was probably sufficient, in at least one case, to permit a northward drainage. The length of the epochs of deglaciation can be only roughly estimated, but the shortest was probably as long as postglacial time, and the others were doubtless much longer. The main trenching of the broad valleys was interglacial, and the minimum amount of interglacial elevation is placed at 250 feet. The land is probably more than 250 feet higher at the present time that it was during the time of the formation of the broad valleys of Cayuga Lake region.

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AN INTERGLACIAL VALLEY IN ILLINOIS.

In this paper it is our purpose to trace the complex history of the present Embarras River valley, in southeastern Illinois, which lies partly on the newer Wisconsin drift and partly on the older Illinoian drift, crossing the terminal moraine of the former about midway of its course. North of the moraine the Embarras Valley is entirely postglacial, with little relation to any former valley. South of the moraine the youthful postglacial valley, as far as it extends, lies within a wider and more mature interglacial valley, which, in turn, usually lies within a still more mature preglacial rock valley.

There is evidence in Illinois and vicinity of several advances and retreats of the ice within the glacial period. During each retreat the melting of the ice freed rock waste, which had been carried along beneath the ice or frozen into the glacier, and deposited this waste as a sheet of till over all the land uncovered by the melting away of the ice. One of the oldest of these till-sheets is the Illinoian, now exposed over most of the southern and western parts of the state, but concealed by subsequent sheets in the northeast, the most extensive of which is the Wisconsin. In the southern two-thirds of the state the Illinoian and Wisconsin sheets are apparently the only ones represented, and their common boundary is the great terminal moraine, built during a prolonged halt of the ice-front at its farthest advance in the Wisconsin stage, and called here the Shelbyville moraine. The time between these two ice invasions, represented by the two drift layers, corresponds with two or more stages represented elsewhere by differentiable till-sheets, but known here only by erosion and weathering in the older drift. In other words, in southern Illinois, we have an old till-sheet extending far south, the Illinoian; a much younger till-sheet extending southward about to Paris, Mattoon, and Shelbyville, the early Wisconsin; and a strong terminal moraine lying along their common boundary. Fig. 1 shows the distribution of these features. For

convenience the time between the two glacial stages mentioned may be called an interglacial epoch, remembering that in other places it may be broken up into several stages of advance with shorter interglacial stages.

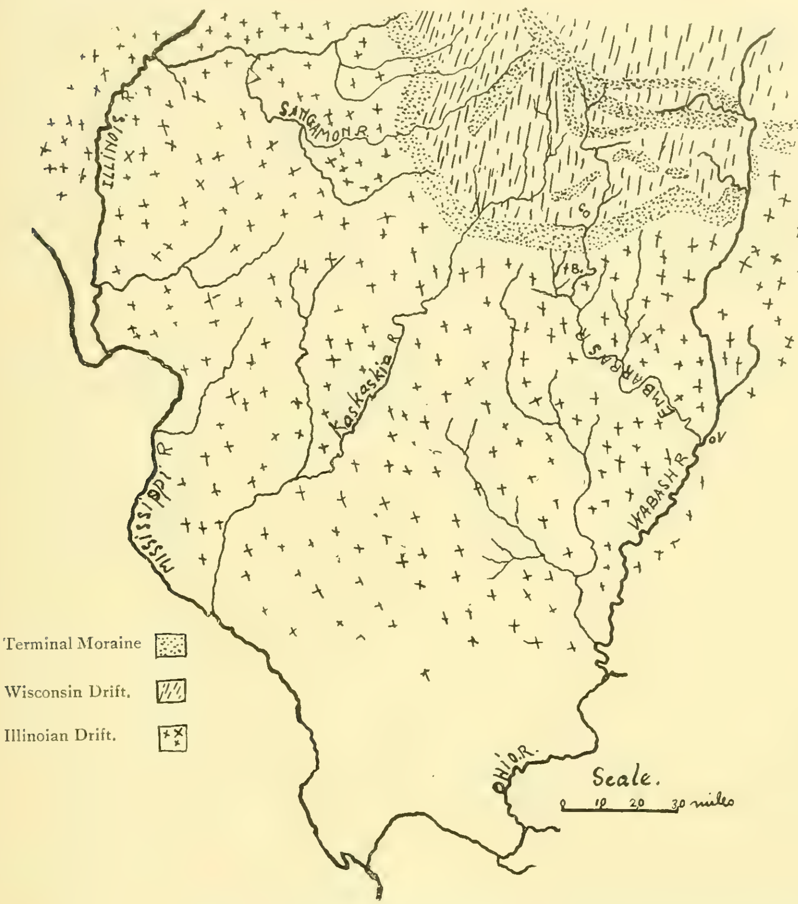

FIG. 1.—Cartogram showing distribution of Early Wisconsin and Illinoian Drift and the Shelbyville moraine and others, also the position of the Embarras River with reference to these areas. Initial letters for towns and cities mentioned in text. Adapted from Leverett, Ill. Glac. Lobe. Monog. 38, U. S. G. S.

Since the general slope of the state is from the north to the south, most of the streams flow in that direction, and of those taking their sources on the new drift several necessarily break

through the terminal moraine and proceed across the old drift to the Wabash, Ohio, or Mississippi Rivers. Among these streams which rise within the moraine loop and find their way out through it is the Embarras, to which the study now turns Rising in several more or less swampy regions, or from tile drains in Champaign county, and receiving several small streams en route, the Embarras proceeds southward across the nearly level tracts of the Wisconsin drift-sheet, and through several minor terminal moraines, until it finally breaks through the large Shelbyville moraine south of Charleston in a clear-cut youthful gorge a hundred feet or more in depth. From this point it continues a more quiet, meandering stream across the plains of the Illinoian drift, to its debouchure into the Wabash River, near Vincennes, Indiana.

Through the early part of its course the Embarras makes its way, leisurely in dry weather, but rapidly in rainy weather, along open, stream-made ditches, or in semi-canals opened by dredging-shovels, in a channel not large enough to carry the flood waters. The stream can hardly be said to have a valley, only a channel, in this part of its course, but after twenty-five to thirty miles have been covered the ditch has become enlarged and a valley formed, which gradually becomes wider and deeper until the moraine is reached. During all this distance extreme youth is a chief characteristic; the valley walls are very steep—so steep, in fact, that landslides are common, and the side streams are short. The main valley attains a depth of seventy-five or eighty feet before it reaches the moraine and is cut in the drift; but occasionally bed-rock is reached, and at such places the valley often narrows to a few feet, and the stream goes through a little rock-floored gorge with rapids or tiny cascades. In the moraine the valley is perceptibly deeper, and near the southern margin of it attains a depth of over one hundred feet, while at several points within the ten or twelve miles through the moraine the water runs on a rock floor, being definitely constricted within a rock gorge at two points.

As the stream comes out upon the older drift, the valley decreases markedly in depth, and increases slightly in width.

The decrease in depth is due, of course, to the absence of the newer drift-sheet and its thickened border, the moraine; the slight increase in width may doubtless be ascribed to the same cause. The valley continues to widen as the stream increases in size, but does not deepen much in the fifty-mile remainder of its course. Its fall is about that of the general slope of the land. Very rarely does the stream touch bed-rock, and at no point is the valley perceptibly constricted because of encountering the more resistant layers. In low water the stream quietly meanders along to its mouth. At a number of points within the first ten miles south of the moraine opposite valley bluffs are apparently of different heights. This was discovered to be due to the fact

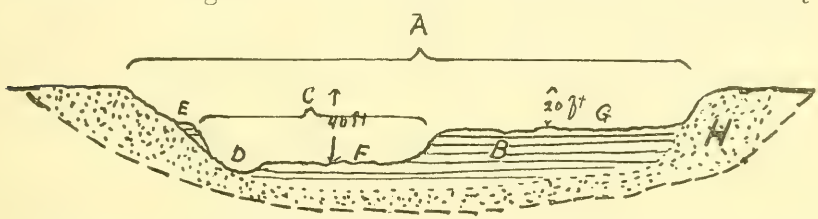

FIG. 2.—- - - -, supposed boundary of preglacial valley; *A*, interglacial valley filled with; *B*, Wisconsin overwash material; *C*, present valley—postglacial; *D*, present stream bed; *E*, remnant of terrace on east side; *F*, present flood plain; *G*, second bottoms; *H*, Illinoian drift sheet. Vertical exaggeration about 25.

that the present gorge-like valley is within an older, more mature valley, whose sides are reached by the inner valley only on the east, and not continuously there. Hence along the west side there are practically two continuous bluffs, the inner one being from a few rods to three-fourths of a mile within the outer one. But on the east side the stream has pushed its inner bluff much nearer the outer one, reaching it at a number of points and blending with it in one continuous descent from the uplands to the present flood-plain. Where this stage has not been reached there are two bluffs on the east side, as on the west, but they are rarely far apart. When the bluffs have coalesced on one side and not on the other, opposite bluffs seem to stand at discordant levels. Fig. 2 illustrates the case. The second or outer bluffs often have a scarp nearly as steep as will stand, say 20–25°, but are usually of gentler slope.

In the latitude of Bradbury, some three miles south of the outer margin of the moraine, the second bluff attains nearly the same height above the first as the first does above the stream. Farther north the first bluff rises higher with reference to the stream and the outer bluff, until, near the moraine, the second becomes almost imperceptible, while farther south the first gradually decreases in height until it becomes practically *nil*. Fig. 2 is a cross-section, somewhat idealized, about opposite Bradbury, at a point where the two eastern bluffs coalesce. Fig. 3 is a bird's-eye view much conventionalized, of the conditions along the west side of the stream, as discussed above.

What is the relation of all this to glaciation? Evidently there are two periods of erosion represented. Is one postglacial? Where, in time, is the other? The nature of the materials in the two sets of bluffs and their relation to surrounding features alone can solve the problem.

Certainly there must be a preglacial valley somewhere near this present stream, unless the whole plan of the preglacial drainage has been upset. The Ohio, Mississippi, Illinois, and lower Wabash in this latitude are, in general, about where they were in preglacial time; hence the general direction of other large streams must be similar to that of their earlier courses, but they are not necessarily in exactly the same beds. The older drift, according to the records of borings and coal shafts, and the exposed sections in stream and railroad cuts, is from twenty to fifty feet thick, rarely more, often less. Between the outer or second bluffs which continue down the stream is a valley, increasing from a mile to three miles in width, and in the deeper portion of its cross-section about fifty feet deep, rarely revealing bed-rock in its floor or sides. Both are practically of continuous drift, corresponding in composition, physical characteristics, and state of weathering with the general drift-sheet on either side. The valley may be followed for fifty to sixty miles with no material change of character, so far as these features are concerned.

There are three time-periods to be considered in the solution of the origin of the valley in question. First, is it a preglacial valley? Second, was it formed since the retreat of the last ice-

sheet? Third, is it interglacial, formed after the advance of the ice that left the Illinoian and before that which left the Wisconsin drift? If it can be shown that the valley is neither preglacial nor postglacial, but is subsequent to the deposition of the Illinoian drift and prior to that of the Wisconsin, its position will be established. The three possibilities will be taken up in the order mentioned.

Since this valley, walled by the second bluffs, is cut in the Illinoian drift-sheet, it must have been formed subsequent to the laying down of that till-sheet. The character of the walls also precludes the possibility of its being due to rejuvenation

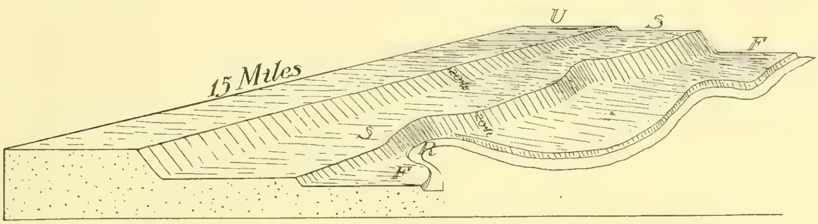

FIG. 3.—Looking N. W. from above east bluff at south end of the Wisconsin overwash in the interglacial valley. R = Embarras River, F = present flood plain, S = "second bottoms"—the terrace top, U = upland surface. Vertical scale very greatly exaggerated.

just prior to the first advance of the ice, as may be the case with those gorges cut in rock, but more or less filled with drift of a late age, such as have been reported in New York. Again, since the valley is so rarely cut down to bed-rock, when the latter is usually very near the surface outside the valley, it is probably in a preglacial, well-matured valley, whose limits are reached only when the present valley encounters ledges. Furthermore, since the valley in the Illinoian drift apparently lies within the preglacial valley, the latter must have been nearly, but not completely, filled and obliterated by the drift-sheet of this early ice invasion. Had it been completely filled, how could the stream now be so continuously within it? It is also true that no large percentage of the drift-filling has been subsequently removed, else the walls of the preglacial rock valley would have been more frequently discovered. Likewise, it is reasonable, if not imperative, to suppose

that when the valley in the Illinoian drift was first formed it extended to a greater depth than the present stream has cut, because the latter, in the few miles of double gorge, is not yet running on Illinoian drift, not having succeeded in cutting through a subsequent filling of the valley in the Illinoian.

This leads to a consideration of the nature of the inner, lower bluffs which accompany the present stream some miles beyond the terminal moraine, and are represented by the second bottom terrace front in Fig. 3, *S*. They are of gravels and sands and, farther south, clayey, fine sands, and partially sorted and stratified drift material corresponding in composition and stage of weathering with that of the earlier Wisconsin, being similar also to deposits on the uplands spread out as an apron in places along the southern margin of the moraine. The second bottoms between the inner and outer bluffs on each side of the stream, where they are not blended into one bluff, are made of the same materials. Wells, on these bottoms, show a section of the same materials to a depth of fifteen to thirty feet. No deeper wells were found in it. Furthermore, the relation of this terrace material, thick near the moraine and feathering out to nothing southward, points to the same conclusion—namely, that the materials of the walls of the inner gorge are layers of overwash material carried out beyond the terminal moraine by the overloaded stream flowing from the melting ice, and deposited by that stream in order to aggrade its course, and thus increase its carrying power to a strength equal to its remaining load. Since this material is of Wisconsin age and is laid down within a valley already formed, that valley cannot be postglacial. The third and only remaining alternative is that the valley represented by the outer bluffs is one formed between the deposition of the Illinoian and that of the Wisconsin drift-sheets, and hence may be called an interglacial valley. Its width and general maturity differentiate it from the known postglacial valleys, while its relative lack of greater maturity, even though in unconsolidated materials, declares it not to belong to the preglacial drainage. The same facts speak for an interglacial time period considerably longer than the postglacial period has been.

Subsequent to the formation of the overwash plain in the interglacial valley and the associated retreat of the ice, the habit of the stream has been changed, because its load has been greatly reduced. Probably its volume has also been somewhat cut down, but not to correspond with the reduction in burden; hence, whereas the stream was aggrading its course during the Wisconsin stage, it has been degrading during the postglacial stage, and has so far succeeded in removing the previously deposited material that the stream now flows in a gorge, a half mile or more in width. The stream is still widening this valley, and the second bottoms (Fig. 2, *G*) still remain to be removed.

The second bottoms constitute terraces of better agricultural soil than that of the vicinal upland. They correspond in orign with those described by early writers in many New England valleys, and especially those in the Connecticut and tributaries so thoroughly studied recently by Professor W. M. Davis. They may be correlated with many terraces in Illinois valleys, because nearly all streams heading on the new drift and flowing out through the moraine are terrace-bordered. The conditions differ to some extent from those reported by Professor Davis in that the postglacial excavation has not proceeded sufficiently as yet to encounter the walls and floors of the old valley. Therefore there are no defending ledges, no series of terrace steps, and very few cusps. The stream has cut back as far, or a little farther, each time than on the previous swing, and hence there is one long step from the second bottoms or terrace-top to the present flood-plain. It is unfortunate that more attention has not been given to the terraces of the Illinois, Iowa, and Wisconsin streams. There are many such terraces, and no doubt a careful study of them would yield valuable returns.

Summary.—The history of the present Embarras River valley is a complex one. North of the moraine it is entirely postglacial, and probably bears little relation to its precursor of interglacial time, still less to the preglacial valley. Very likely near the moraine and in it where the valley is deepest the stream has cu its recent channel mostly in the filling of a former valley, but the occurrence of occasional rock-ledges witnesses to the errors of

the stream in attaining its former course. Farther back from the moraine, even to the stream's sources, the drift is so deep and the channel is so shallow that the absence of bed-rock in the bottom of the valley proves nothing as to the position of the earlier stream and its valley. South of the moraine the till is much thinner, and a valley with such depths as those of the Embarras would often, if not almost constantly, reach bed-rock, were it not within an earlier valley. Hence there was, first, a broad, well matured preglacial valley similar to those at present in nearby carboniferous rock in unglaciated parts of Indiana, Kentucky, and southern Illinois. Second, this valley was nearly filled with drift of Illinoian age. Third, after the retreat of the ice of the Illinoian stage and before the Wisconsin invasion, a valley was excavated in the above-mentioned filling. This probably extended some distance north of the present terminal moraine, possibly as far as the present sources of the Embarras. Fourth, this interglacial valley was partly filled with overwash material (entirely filled, north of the moraine, with drift) of Wisconsin age. And, fifth, the present youthful postglacial channel has been cut in the filling of the interglacial gorge, but the process has not gone far enough to reach bed-rock where the stream is fairly within the earlier valleys.

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Reviews.

SUMMARIES OF PRE-CAMBRIAN LITERATURE FOR 1902–1903. II.

[*Continued from p. 62.*]

C. K. Leith.

A. P. Coleman and A. B. Willmott. "The Michipicoten Iron Ranges." "Geological Series," *University of Toronto Studies*, 1902, pp. 39–83. See also *Report of the Bureau of Mines*, Ontario, 1902, pp. 128–51.

Coleman and Willmott describe and map the Michipicoten iron ranges. The rocks are classified as follows:

Archæan	Laurentian	Gneisses and granites
	Upper Huronian	Basic eruptives
		Acid eruptives
		Doré conglomerate
	Lower Huronian	Eleanor slates
		Helen iron formation
		Wawa tuffs
		Gros Cap greenstones

The Gros Cap greenstones are basic eruptives with ellipsoidal structure corresponding in position and character to the Ely greenstones of the basement complex of the Vermilion district of Minnesota. They are in part basal to the other rocks of the district, but in part also they are interbedded with the rocks of the Helen iron formation. The Wawa tuffs are acid schists having the composition of quartz-porphyry or felsite, usually in the form of tuff, ash, or breccia, and sometimes show stratification, taken to indicate deposition by water.

Slates of distinctly sedimentary origin, occurring in thin bands near Eleanor Lake and called the Eleanor slates, are referred to the Lower Huronian. Their relations to the Helen iron formation are not known.

The Helen iron formation, 500 feet thick, comprises banded granular silica with more or less iron ore, black slate, siderite with varying amounts of silica, and grünerite schist. All are found well developed at the Helen mine, and all but the grünerite schist have been found in the Lake Eleanor iron range also, while granular silica and siderite occur in large quantities in every important part of the range, though small outcrops sometimes show the silica alone. All of the rocks of the iron formation contain considerable amounts of iron pyrites. The grained silica and the granular silica is similar in certain respects to the jaspers and ferruginous cherts of the United States, and their origin is believed to be the same. They differ in being often soft, pulverulent, and brecciated. The black, graphitic slate, forming a thin sheet just under the iron range proper west of the Helen mine and at other points in the region, seems closely related to the granular silica, being composed of the same material with a large admixture of carbon which smears the fingers.

Iron ore is mined in the Helen mine, and this mine is described in detail. The

ore body is located at the east end of the deep Sayers Lake basin, partly above and partly below the old water level. The lake has now been drained, and the ores appear in a great amphitheater opening out to the west. The rocks immediately associated with the hematite are siliceous ore, ferruginous cherts, or grained silica rocks. These are mapped as immediately surrounding the iron ore, and also as forming for the most part the north wall of the amphitheater. The east wall of the amphitheater is composed of iron carbonate which shows gradations into siliceous ore and into hematite ore. The south wall is composed of Wawa tuffs.

The ores are believed to have resulted from the secondary alteration of an original iron formation consisting mainly of iron carbonate, grained silica, and limestone, in part interbedded with the Wawa tuffs, but mainly deposited above them. The iron formation and the tuffs were folded up together, with the result that the tuffs were formed into a trough underlying the iron formation, and the iron formation within this trough was folded and brecciated. Percolating waters then altered the iron carbonates. Probably the chief solvent of the carbonates was acid ferric sulphate or sulphuric acid resulting from the oxidation of the iron pyrites, which are found in considerable quantity throughout the iron formation. The ore body has resulted directly from the alteration of iron carbonate, the oxidation of the iron sulphide having yielded but little ore. The oxidation of the iron took place where solutions of iron carbonate came into contact with waters bearing oxygen.

The principal areas of iron formation possibly bearing iron ore at Gros Cap, Sayers, and Boyer Lakes, just east of the Helen mine, around Brooks Lake, south of Long Lake, just east of Goetz Lake, in Parks Lake, and between Parks and Kimball Lakes.

The Upper Huronian rocks are represented principally by the Doré conglomerate, occurring typically at the mouth of the Doré River and thence eastward beyond Michipicoten Harbor, and to a less extent in other parts of the district. This conglomerate is unconformably above the Lower Huronian rocks of the district. It contains pebbles of granite, felsite, conglomerate, granular silica of the iron formation and breccia.

The Doré conglomerate is cut by acid intrusives in dikes and bosses. These are the latest rocks of the region.

The Laurentian granites and gneisses have not been studied in detail in the Michipicoten district, but their associations with both Lower and Upper Huronian prove them to be post-Huronian eruptive masses.

Comment.— As noted in the above paper, there is very close similarity in lithology and succession between the rocks of the Michipicoten district and the rocks of the Vermilion iron-bearing district of Minnesota, although described under different names. The rocks above called Lower Huronian and Upper Huronian are called respectively Archæan and Lower Huronian by the United States geologists.

There is substantial agreement in the matter of the origin of the ores in the two districts.[1] The Wawa tuffs are also similar to the Palmer gneiss of the Archæan of the Marquette district. The granites and gneisses described as Laurentian for the Michipicoten district are similar in character and relations to granites in United States districts referred to the Lower Huronian.

[1] J. Morgan Clements, "The Vermilion Iron-Bearing District of Minnesota, *Monograph XLVI, U. S. Geological Survey*, 1903; C. R. Van Hise, "The Iron-Ore Deposits of the Lake Superior Region," *Twenty-first Annual Report of the U. S. Geological Survey*, Part III, pp. 305–434.

A. P. COLEMAN. "Rock Basins of Helen Mine, Michipicoten, Canada." *Bulletin of the Geological Society of America*, Vol. XLIII (1902), pp. 293–304.

Coleman discusses the origin of the rock basins of Boyer and Sayer's Lakes of the Michipicoten district of Canada, the former containing the Helen iron-ore body. He holds the lake basins to have resulted from the solution of the iron-bearing rocks long before glacial time.

A. B. WILLMOTT. "The Nomenclature of the Lake Superior Formations." JOURNAL OF GEOLOGY, Vol. X (1902), pp. 67–76.

Willmott discusses the nomenclature of the Lake Superior formations, this being practically a consideration of Van Hise's "Iron-Ore Deposits of the Lake Superior Region."[1] He argues principally against the correlation of the Animikie series with the Upper Huronian of the original Huronian area. He states that there can be no doubt that Logan in 1863 included within his Huronian two series — the one typically represented by the banded jaspers, the other by the slate conglomerate and the jasper conglomerate. This has been uniformly followed from that time forward by all Canadian geologists, and by many American, the vertical green schists and their interbedded banded jaspers being considered Lower Huronian. Professor Willmott doubts the advisability of attempting the separation of the green volcanics and sediments, except in limited areas of economic value. Here each would be given formational names, just as Van Hise has done with the Ely greenstone and the Soudan iron formation. In other places the volcanics and eruptives will take the name of the sediment with which they are associated. The lowest sedimentary series of the Lake Superior region is the Lower Huronian. These sediments were included in the areas mapped as Huronian by Logan in 1863, and, although not actually found in place by him, were recognized from their fragments, and to him should be given the credit. As so used, the term "Lower Huronian" is nearly equivalent to the term "Archæan" as used by Van Hise, and the term "Upper Huronian" is equivalent to Van Hise's "Lower Huronian." Accordingly, the Animikie, or the Upper Huronian of Van Hise, is younger than the original Huronian series. That the Animikie is later than the true Upper Huronian or original Huronian may be shown in the following ways:

1. Stratigraphically it is the third series of sediments upwards from the bottom of the geological column in the Lake Superior region; the Upper Huronian is the second.

2. Lithologically, the two series are quite different, and so presumably are of different age. There is very little conglomerate at the base of the Animikie; in the Huronian the quartzites, slate conglomerates, and jasper conglomerates are of great thickness. The oolitic jaspers found in the Animikie are quite absent from the Huronian. The shales, so important in the Animikie, are almost unknown in the Huronian. The laccolitic sills of the Animikie are lacking in the Original Huronian.

3. Structurally, the two series are usually said to be alike in that both lie flat and undisturbed. While this is quite true of the Animikie, it is only partially true of the Huronian north of the Georgian Bay, and is untrue of the Upper Huronian about Batchawana and Michipicoten. Coleman[2] and Murray[3] have described cases of

[1] C. R. VAN HISE, "The Iron Ore Deposits of the Lake Superior Region," *Twenty-first Annual Report of the U. S. Geological Survey*, Part III, pp. 305–434.

[2] *Bureau of Mines, Ontario*, 1901, p. 189.

[3] *Geological Survey of Canada*, 1858, p. 95.

vertical dip within the so-called Original Huronian, and others have been observed by myself. These seem to occur around the outer portion of the Huronian basin, and more gentle dips obtain in the central part. Evidently the Huronian has been subjected to forces which the later Animikie has escaped.

4. Assuming that the large areas of eruptive granite-geisses in the Lake Superior region are of the same age, we find that the Upper Huronian has in many cases been pierced by them, but that the Animikie always overlies them.

A. P. COLEMAN. "The Huronian Question." *American Geologist*, Vol. XXIX (1902), pp. 325–34.

Coleman discusses the Huronian question, his argument being mainly against the correlation of the Animikie series of the Lake Superior region with the Upper Huronian series. Evidence that the Animikie is unconformable above his Upper Huronian series is summarized, and emphasis is placed on the points that both the Upper Huronian and the Lower Huronian differ lithologically from the Animikie; they are metamorphosed and schistose as compared with the Animikie; and they are much folded aad highly tilted, in marked contrast to the Animikie.

Comment.—For the most part the terms "Upper Huronian" and "Lower Huronian," as applied by Professors Willmott and Coleman to rocks *outside* of the part of the Original Huronian area of Logan on the north shore of Lake Huron, are to be correlated respectively with the "Archæan" and "Lower Huronian" of the United States geologists, and thus Van Hise's "Upper Huronian" or "Animikie" comes above their "Upper Huronian." For such areas, therefore, there is no marked difference of opinion as to the number and succession of series, but only difference in names. However, when it comes to the correlations of these series with the rocks of the Huronian series on the north shore of Lake Huron the difference is fundamental. Coleman and Willmott, in common with other Canadian geologists, apply the term "Upper Huronian" to the entire series north of Lake Huron mapped as "Huronian" by Logan, and apply the term "Lower Huronian" to underlying greenstones, green schists, and jaspers (as typically developed in the Michipicoten district). This Lower Huronian series, with the addition of certain "Laurentian" granites, corresponds approximately to what Van Hise, following the terminology of the U. S. Geological Survey, has called the "Archæan" in this and other parts of the Lake Superior region. But the sediments which Logan mapped as "Huronian," and which are classed as "Upper Huronian" by Willmott and Coleman, have been divided on the north shore of Lake Huron by Van Hise and Pumpelly, following Alexander Winchell, into the "Lower Huronian" and "Upper Huronian" series, the break being placed at the base of the Upper slate conglomerate, It is with these divisions of the Original Huronian series that the correlation of the Upper Huronian and the Lower Huronian series of the rest of the Lake Superior region has been made by Van Hise. Field work done on the north shore of Lake Huron during 1902 by Professors Van Hise, Seaman, and the writer presents further evidence of the correctness of this correlation. A full discussion of the evidence is not possible here, but it will be presented shortly in a general monograph on Lake Superior geology now in preparation.

ANDREW C. LAWSON. "The Eparchean Interval: A Criticism of the Use of the Term Algonkian." *Bulletin of the Department of Geology*, University of California, Vol. III, pp. 61–52.

Lawson criticises the use of the term "Algonkian." He emphasizes the impor tance of the interval, which he calls the Eparchæan interval, between the "Huronian'

and Animikie series, that is, between the Lower Huronian and Upper Huronian, of the United States Geological Survey, and argues that no one term such as "Algonkian" should include a break of this importance. It is proposed to restrict "Algonkian" to the Animikie and Keweenawan rocks, and to retain Dana's term "Archæan" for all rocks below the Animikie, *i.e.*, below the Eparchæan interval, and also to retain the terms "Laurentian" and "Huronian," as subdivisions of the Archæan, with the significance originally given them by Logan. The correlations of the Animikie with the Keewatin of Minnesota and with the Upper Huronian of Lake Huron is regarded as an error, because of dissimilarity in lithology, stratigraphy, and in relations to intrusives. Following Willmott and others, it is believed that the Animikie is younger than the (Upper) Huronian series of Lake Huron, and thus later than the Eparchæan interval. Emphasis is placed on the marked lithological similarity in the sedimentary series below the Eparchæan break in the Lake Superior and Lake Huron region, and the probable correlation of these rocks with the Original Huronian series. Summarized in tabular form, the correlation proposed is as follows:

Paleozoic.	Cambrian (Upper division or Potsdam only).	
	Unconformity.	
	Algonkian.	Keweenawan.
		Unconformity.
		Animikie = Penokee = Upper Marquette.
Eparchæan Interval.		
Archæan	Huronian = Upper Keewatin = Lower Marquette, etc.	
	Unconformity.	
	Laurentian, so called, granite gneisses, etc. (intrusive in the Ontarian) and the Carlton anorthosites.	
	Ontarian	Keewatin = Lower Huronian = Crystalline schists of south shore invaded by granite gneisses.
		Unconformity.
		Coutchiching.

Comment.—Concerning the correlation of the Animikie with the Upper Huronian the comment on Professors Willmott and Coleman's articles, summarized on a preceding page, is pertinent. Dr. Lawson implies that the Animikie has been correlated by the U. S. Geological Survey with the entire sedimentary Huronian series of the north shore of Lake Huron, while it has been correlated only with the portion of this series above the limestone; and against such a correlation his argument loses some of its force. If the Keweenawan and Animikie series are not Cambrian, as they are held to be by Lawson, but are pre-Cambrian, as held by the U. S. Geological Survey, then Lawson's objection to the term "Algonkian," as replacing in part the old term "Archæan," would prevent its application even to the Animikie and Keweenawan rocks to which he restricts it. As already noted, the nomenclature of Lake Superior and Lake Huron series is being fully discussed in a general monograph on Lake Superior geology now in preparation. Arguments for the adoption and retention of the term "Algonkian" will be summarized, together with new arguments developed in recent field work.

C. R. VAN HISE. "Geological Work in the Lake Superior Region." *Proceedings of the Lake Superior Mining Institute*, Vol. VII (1902), pp. 62–69.

Van Hise briefly sketches the history of geological mapping in the Lake Superior region, calling attention to the difficulty of preparing accurate maps, and concludes that the maps which have been published from time to time since the earliest map of Foster

and Whitney represent reasonably close approximations to the facts as then known, and that, notwithstanding their many imperfections, they have been of service at the time of publication.

J. E. Spurr. "The Original Source of the Lake Superior Iron Ores." *American Geologist*, Vol. XXIX (1902), pp. 335–49.

Spurr discusses the origin of the pre-Cambrian iron ores of the Lake Superior regions. He repeats his conclusion that the Mesabi ores have resulted from the alteration of a green ferrous silicate of the class of glauconite, and further states that his conclusion in reference to the Mesabi iron formation may be "probably applied to most of the other Lake Superior iron ores."

Comment. — This paper is practically a reply to a brief abstract published in the *Engineering and Mining Journal* of an informal talk given by the writer before the Geological Society of Washington. While fully agreeing with Mr. Spurr's major conclusion that the Mesabi ores have resulted from the alteration of ferrous silicate granules, the writer has emphasized certain facts which seem to prevent the application of the name "glauconite" to this silicate.[1]

As to the statement that conclusions applicable to the Mesabi ores apply to most of the other Lake Superior iron ores, presumably this is based on certain similarities in granules and concretionary forms to be observed in the iron-bearing rocks of the Mesabi and Gogebic districts. This similarity the writer has discussed elsewhere,[2] and believes it will afford no support for Dr. Spurr's somewhat sweeping statement.

C. K. Leith. "A Comparison of the Origin and Development of the Iron Ores of the Mesabi and Gogebic Iron Ranges." *Proceedings of the Lake Superior Mining Institute*, Vol. VII (1902), pp. 75–81.

Leith compares the origin and development of the Gogebic and Mesabi iron ores. The ores of the two districts occur in the same geological horizon; they result from the alteration, under weathering conditions, of a ferrous compound of iron, through the agency of percolating waters, and are localized in channels of vigorous circulation of water. But the differences in the development of the ores of the two districts are important. The original ferrous compound of iron is mainly iron silicate in the Mesabi district, and iron carbonate in the Gogebic district, although both substances appear in each district. The localization of the ores in the Gogebic district during their concentration has been within clear-cut pitching troughs with definite shapes, while in the Mesabi district the very gentle folding of the iron formation, its fracturing, and the absence of intrusives combine to make the channels of vigorous flow within the iron formation most devious, resulting in the curious and exceedingly irregular shapes now to be observed in the Mesabi ore deposits.

The original ferrous silicate from which the ores develop in the Mesabi district is in minute homogenous granules, the form of which remains even after the substance is changed. Associated with these granules are undoubted concretions of iron oxide and chert with concentric structure. In the Gogebic district there appear numerous

[1] C. K. Leith, "The Mesabi Iron-Bearing District of Minnesota," *Monograph XLIII, U. S. Geological Survey*, 1903.

[2] C. K. Leith, "A Comparison of the Origin and Development of the Iron Ores of the Mesabi and Gogebic Iron Ranges." *Proceedings of the Lake Superior Mining Institute*, 1902, pp. 75–81. (See summary below.)

concretions with concentric structure, which Van Hise has shown to develop during the alteration of iron carbonate; and associated with these are rare granules of iron oxide and chert in varying proportions, which may represent altered ferrous silicate granules similar to those of the Mesabi district. Evidences of the existence of original ferrous silicate granules in the Gogebic district are not sufficiently numerous to warrant modification of Van Hise's conclusion that the ores have developed from the alteration of iron carbonate.

C. K. LEITH. "The Mesabi Iron-Bearing District of Minnesota." Monograph XLIII, U. S. Geological Survey, 1903.

Leith describes and maps the geology of the Mesabi district of Minnesota. The district is two to ten miles in width, extending from near Grand Rapids on the Mississippi River to Birch Lake, a distance of approximately one hundred miles. The main topographic feature is a ridge known as the Giant's (or Mesabi) Range, which extends the length of the district. The geologic formations represented in the district belong, in ascending succession to the Archæan, Lower Huronian, Upper Huronian Keweenawan, Cretaceous, and Pleistocene. They are all separated by unconformities. The core of the Giant's Range is formed by Archæan and Lower Huronian rocks, except for the portion in ranges 12 and 13, where Keweenawan granite forms the core. On the south flank rest the Upper Huronian rocks, containing the iron-bearing formation, with gentle southerly dips. The Keweenawan gabbro lies diagonally across the east end of the district.

The Archæan rocks consist principally of green rocks of great variety, including dolerites, metadolerites, basalts, metabasalts, diorites, and hornblendic, micaceous, and chloritic schists. The more massive rocks frequently have an ellipsoidal structure, which is characteristic of the green igneous rocks of other parts of the Lake Superior region. In addition to the green basic rocks, there are present small areas of granite and porphyritic rhyolite.

The Lower Huronian series consists of sediments and granite. The sediments are graywackes, slates, and conglomerates, all metamorphosed, with bedding and schistosity practically vertical. They may be as thick as 10,000 feet, but it is thought more probable that the thickness does not exceed 5,000 feet. The Lower Huronian sediments rest unconformably upon the Archæan rocks, as shown by basal conglomerates containing fragments of all the varieties of rocks found in the Archæan. The Lower Huronian granite forms the main mass of the Giant's Range westward from a point near the east line of Range 14 W. It is intrusive into both the Archæan rocks and the Lower Huronian sediments, and has produced strong exomorphic effects in both.

The Upper Huronian or Animikie consists of three formations — the Pokegama quartzite at the base, above this the Biwabik formation (iron-bearing), and above this the Virginia slate.

The Pokegama quartzite comprises vitreous quartzite, micaceous quartz-slate, and conglomerate. The thickness ranges from 0 to 500 feet, averaging about 200 feet. The conglomerate at the base indicates unconformable relations of the Pokegama formation to the Archæan and Lower Huronian rocks.

The Biwabik formation, the iron-bearing formation, comprises ferruginous, amphibolitic, sideritic, and calcareous cherts, siliceous, ferruginous, and amphibolitic slates, paint rocks, "greenalite" rocks, sideritic and calcareous rocks, conglomerates and quartzites, and iron ores. Cherts make up the bulk of the formation. The

original rock of the formation is shown to consist largely of minute granules of green ferrous silicate, thus confirming Spurr's conclusion. The material was called "glauconite" by Spurr, but is here determined to be a hydrous ferrous silicate entirely lacking potash, and thus not glauconite. It is named "greenalite" for convenience in discussion. The cherts and iron ores are shown to develop mainly from the alteration of the greenalite granules. The slates are in thin layers interbedded with the other phases of the iron formation. The paint rocks result from the alteration of the slates. The conglomerates and quartzites form a thin layer from a few inches to perhaps 15 feet or more in thickness at the base of the formation. They pass upward into ferruginous cherts of the iron formation rather abruptly, though usually at the contact the chert and quartzite are interleaved for a few feet. The conglomerate of the iron formation rests upon Pokegama quartzite, indicating a slight erosion interval between the Biwabik and Pokegama formations, although the interval is not shown by discordance in bedding, which is parallel in both. Heretofore the quartzite and conglomerate in the iron formation have not been discriminated from the rocks of the Pokegama formation. In the eastern portion of the range the iron formation is in contact with the Keweenawan gabbro and granite, and near this contact has suffered profound metamorphism. The characteristic rocks of this area are amphibole-magnetite-cherts. The thickness of the formation may vary from 200 to 2,000 feet. The average may be 1,000 feet.

The Virginia slate is essentially a soft slate or shale formation, but it contains graywacke phases, near its base a little limestone, and near its contact with the gabbro is metamorphosed into a cordierite-hornfels. The normal slate phases of the formation may be distinguished with difficulty in isolated occurrences from the slate layers in the Biwabik formation. The separation of the two is of importance to the explorer, and hence an attempt is made to determine criteria for their discrimination. The thickness of the Virginia formation cannot be measured within the district, but from analogy with the Penokee-Gogebic district and the extent of the low, flat-lying area south of the Mesabi range supposed to be occupied by the slate, the formation is believed to have a very considerable thickness. The slate grades, both vertically and laterally, into the Biwabik formation.

The entire Upper Huronian series is well bedded, conformable in structure (although having a thin conglomerate between the Biwabik and Pokegama formations), and dips in southerly directions at angles varying from 5° to 20°, and exceptionally at higher or lower angles. The series is gently cross-folded, and the axes of the cross-folds pitch in southerly directions. Accompanying the folding is considerable jointing, especially in the brittle Pokegama and Biwabik formations. Indeed, in these two formations the folding is brought about mainly through relatively minute displacements along joints, while in the Virginia formation the folding has taken place mainly by the actual bending of the strata.

The thickness of the Upper Huronian series within the limits of the district mapped may average about 1,500 feet; but if the total thickness of the slate formation outside the limits of the district be taken into account, the total thickness of the Upper Huronian series is probably several times this figure.

The relations of the Upper Huronian series to the subjacent formations are those of unconformity, as evidenced by basal conglomerates, discordance in dip, difference in amount of deformation and metamorphism, distribution of the series, and relations to intrusives.

The Keweenawan rocks consist of gabbro, diabase, and granite, all of which are intrusive into the rocks with which they come into contact. The north edge of the gabbro runs diagonally across the east end of the district from southwest to northeast, resting upon the edges of each of the members of the Upper Huronian series, and at Birch Lake against the Lower Huronian granite. North of the gabbro margin, in Range 12, are isolated exposures of diabase which may represent sills associated with gabbro intrusion. The granite forms the crest of the Giant's Range through Ranges 12 and 13. This granite has not heretofore been discriminated from the Lower Huronian granite. The exomorphic effect of the gabbro and the granite upon the Upper Huronian series has been profound.

J. Morgan Clements. "The Vermilion Iron-Bearing District of Minnesota." *Monograph XLV, U. S. Geological Survey*, 1903.

Clements describes the geology of the Vermilion iron-bearing district of Minnesota. Elaborate general and detailed maps, accompanying this report, are based on field work by Clements, Van Hise, Bayley, Merriam, and Leith.

The district ranges from two to eighteen miles in width, and extends from a little west of Lake Vermilion in a direction a little north of east to Gunflint Lake on the international boundary, a distance of about one hundred miles.

The rocks of the district are described under the headings "Archæan," "Lower Huronian," and "Upper Huronian," representing series separated by marked unconformities.

The Archæan of the Vermilion district is divided into three formations, as follows, given from the base up: the Ely greenstone, the iron-bearing Soudan formation, and the granites of Vermilion, Trout, Burntside, Basswood, and Saganaga Lakes.

The Ely greenstones consist of basic and intermediate igneous rocks widely distributed in anticlinal areas, as shown by the distribution of the overlying sediments. They were originally rocks corresponding in character to intermediate andesites and basic basalts. They have been extremely altered, but retain in many cases in striking perfection the original structures, such as ellipsoidal parting, and spherulitic and amygdaloidal structures. A study of their various textures and structures shows that these greenstones are unquestionably of igneous origin, and are largely of volcanic character. Many of them have been rendered schistose by pressure. The greenstones have also been strongly affected by the contact metamorphism due to the intrusion of great granite masses. As a result of this intrusion, there have been produced from the greenstones amphibole-schists, which form a marginal facies of the greenstones, lying between them and the adjacent granites. The greenstones have also been metamorphosed by the Duluth gabbro of Keweenawan age, and granular rocks have thus been produced which in most cases show the original textures of the greenstones, but contain also a development of fresh biotite, hypersthene, brown-green hornblende, and magnetite.

The Soudan iron formation is widely distributed in the western part of the district, but is practically wanting in the eastern half. It is found mostly in narrow belts, which consist largely of greenstone so intimately associated with the iron formation that it has been impossible to separate them on the map. The formation consists of (1) a very subordinate fragmental portion made up of some conglomerate, clearly recognizable as having been derived from the underlying greenstones, grading up into sediments of finer character; and (2) lying above this fragmental portion, the iron-

bearing formation proper, which consists of siliceous rocks, largely white cherts — though varying in color from white, green, yellow, and purplish to black — with red jasper and carbonate-bearing chert, grünerite-magnetite-schist, hematite, magnetite, and small quantities of pyrite. These iron-bearing rocks are clearly of sedimentary origin. They do not now present their original characters, but are presumed to have been derived from rocks that were largely carbonate-bearing, ferruginous cherts. The relation of the iron formation to the adjacent greenstones is clearly that of a sedimentary overlying an igneous series. The few basal conglomerates of the iron formation that have been found consist of pebbles derived from the underlying greenstone, showing conclusively their relationship. This relationship is obscured, however, in most places, by the absence of the conglomerates, and by the fact that the iron formation has been very closely infolded in the greenstone. In consequence of the extreme folding and of the impossibility of determining different horizons in the iron formation, it has been impracticable to ascertain its thickness. The iron-ore deposits of the Vermilion district show a striking analogy with those of the Marquette district. Like them, they may occur in two positions with respect to the iron-bearing formation. They are found, first, at the bottom of this formation, and, second, within it, the ores in both cases being the same in character. The Ely deposits are typical of the deposits occurring at the base of the formation. They are found at the bottom of a closely compressed syncline of the iron formation where it lies in the relatively impervious greenstone. The source of the iron was, in the first instance, the Ely greenstone. From this it was removed through the action of water and collected in the Archæan sea to form the sedimentary deposits of the Soudan formation. After the folding of the formation this disseminated iron was carried by downward percolating waters into places favorable for its accumulation, such as the bottom of this synclinal trough, where it was precipitated by oxygen-bearing waters coming more directly from the surface. *Pari passu* with this precipitation silica was removed, affording space for the accumulation of the iron to form the ore deposits as now known. The Tower and Soudan deposits differ only in detail from the Ely deposit.

Granites, intrusive into the Archæan, occupy a wide area, and are named from the topographic features with which they are conspicuously associated. That these intrusives are older than the Ogishke conglomerate (Lower Huronian), which succeeds in age the Soudan formation, is shown conclusively by the fact that pebbles derived from them occur in this conglomerate. The general period of intrusion of all of these acid igneous rocks is placed between the time of the deposition of the latest sediments of the Archæan and that of the deposition of the earliest sediments of the Lower Huronian series.

The Lower Huronian occurs in two detached areas, one of which, known as the Vermilion Lake area, extends from the western limit of the area mapped, in the vicinity of Tower, to within about eleven miles of Ely on the east, and the second of which, known as the Knife Lake area, begins about seven miles west of Ely, and extends eastward to the eastern limit of the area mapped. At the base of the series there lies a great conglomerate, known as the Ogishke conglomerate, containing pebbles and finer detritus from all of the rocks of the Archæan. Above this conglomerate, in the eastern portion of the district, there are found in a few localities small masses of the iron-bearing Agawa formation. This formation is petrographically the same as the Soudan formation. In it, however, there is in places a development of the carbonate-bearing facies. No iron ores have been found in it. Overlying the Ogishke conglomerate, in the

western portion of the district, and the intervening iron-bearing Agawa formation where present in the eastern portion of the district, there occurs a thick series of slates of varying character, to which the name "Knife Lake slates" has been given. These slates have been very closely folded, and have been more metamorphosed where intruded by granites of Giant's Range, Snowbank Lake, and Cacaquabic Lake, and by the Duluth gabbro. These igneous rocks occupy a considerable area, and their intrusive relation to the Lower Huronian are unquestionable. The Lower Huronian sediments now stand nearly vertical.

The Upper Huronian or Animikie series is found in the extreme eastern portion of the district, where it is continuous with the Animikie of the Mesabi district to the west and Thunder Bay to the east. At the bottom of the series occurs an iron-bearing formation known as the Gunflint formation. Above this occurs a great slate-graywacke formation, to which the name "Rove slate" has been given. The Gunflint formation is correlated with the Biwabik formation of the Mesabi district. It has a very limited development in the Vermilion district, and its most interesting phases are especially well developed in the vicinity of Akeley Lake. In general the formation has a monoclinal dip to the south-southeast at a low angle. It has been extremely metamorphosed by the Duluth gabbro, and where most metamorphosed the rocks are composed of coarsely crystalline bands of quartz, of varying width, alternating with coarsely crystalline bands of magnetite ore reported to vary from one inch up to ten or twelve feet in thickness, and of bands of dark-green, brown, or black rocks that consist of combinations of quartz, augite, hypersthene, hornblende, olivine, and magnetite as the principal minerals, but associated occasionally with some ferruginous carbonate, actinolite and grünerite.

The Duluth gabbro and the Logan sills, referred to the Keweenawan, occur in the eastern portion of the district. The gabbro is found to metamorphose all of the sediments already enumerated, and is thus shown to be one of the youngest rocks of the district. It is also found to be intrusive in the Keweenawan volcanics. A number of facts are enumerated to show that the gabbro and the Logan sills are of essentially the same petrographic character, although they exhibit minor differences that are readily explicable when one considers the relative amounts of the two rocks. After a consideration of these facts, and of the stratigraphic relationship of the rocks, the conclusion is reached that the gabbro and the sills are of essentially the same composition and age, having been derived from the same parent mass of magma. In certain localities in the Duluth gabbro there are found masses of titaniferous magnetite of varying but small size with some associated minerals. These masses grade into the surrounding gabbro, and were formed as the result of processes of segregation.

Cutting the Duluth gabbro are acid dikes and dikes of basalt and diorite.

The entire district has been much folded and metamorphosed, resulting in a marked north of east and south of west trend of the Archæan and Lower Huronian formations, marked principally by schistosity.

Comment on the Vermilion and Mesabi Reports.— Detailed work in these districts has developed a number of points bearing on the general stratigraphy and correlation of the rocks of the Lake Superior and Lake Huron districts.

In the Vermilion district the rocks now called Lower Huronian had previously been referred to the Upper Huronian by the U. S. Geological Survey, and the sedimentary Soudan iron formation, now mapped as Archæan, had previously been called Lower Huronian, and separated from the greenstones and granites supposed alone to

represent the Archæan. The Lower Huronian and Archæan of the present report correspond approximately with the Upper and Lower Keewatin of the Minnesota Survey, although there are minor differences in the reference of the several geological units to these divisions.

In the Mesabi district the rocks underlying the Animikie of the Upper Huronian had previously been lumped together as Archæan by the U. S. Geological Survey. They are now shown to be divisible into (1) a sedimentary formation, referred, with its associated intrusives, to the lower Huronian, showing remarkable similarity in lithology and structure to the Lower Huronian of the Vermilion district; and (2) an igneous series, referred to the Archæan, with marked similarity to the igneous rocks of the Archæan of the Vermilion district. The Lower Huronian and Archæan thus correspond roughly to the Upper and Lower Keewatin of the Minnesota Survey. This division of the Keewatin was not made in the Mesabi district by the Minnesota Geological Survey, although Dr. Grant noted the occurrence of rocks characteristic of the two divisions, and suggested the possibility of their separation.

The correlation of the Animikie series of the Vermilion and Mesabi districts with the Upper Huronian series of the north shore of Lake Huron is the same as in previous reports of the U. S. Geological Survey, and is the feature of the correlation which has been severely criticised by Canadian and other geologists, including Coleman, Willmott, Winchell, and Lawson, who hold the Animikie to be unconformably above the original Huronian series of the north shore of Lake Huron, from which the term "Huronian" comes. Comments on their arguments are made in connection with summaries of their articles on a preceding page.

The reference of the sedimentary Soudan iron formation to the Archæan, instead of including it in the Huronian and thus making a threefold division of the Huronian, as is now possible in the Marquette district, has also been criticised. The defense of such a use of the term "Archæan" involves a discussion of the principles of pre-Cambrian nomenclature not here warranted. Such a discussion will be made in a final monograph on Lake Superior geology now in preparation by the U. S. Geological Survey.

N. H. WINCHELL. Some Results of the Late Minnesota Geological Survey. *American Geologist*, Vol. XXXII (1903), pp. 246–53.

Winchell summarizes some results of the work of the late Minnesota Geological Survey. Those referring to the pre-Cambrian are as follows (the numbers are Professor Winchell's):

5. The discrimination of two iron-bearing formations in northern Minnesota, thus separating the Mesabi range stratigraphically from the Vermilion. This observation was continued into Wisconsin and Michigan by a visit to those states, and the same dualty was pointed out in the iron regions of those states, and was announced for the first time in the Minnesota report for 1888. It has since been discovered that there is still a third iron horizon in northeastern Minnesota, not mentioning the titanic iron ore of the gabbro. It is the upper Keewatin, the others being in the Lower Keewatin and the Taconic.

6. The separation of the Archæan of Minnesota into two non-conformable parts, viz., the Upper and Lower Keewatin, with a great basal conglomerate between them.

7. The determination of the oldest known rock of the Lake Superior region, a greenstone called Kawishiwin, the bottom rock of the Keewatin, the supposed earliest crust of the globe.

8. The great quartzite formation, which cuts quite a figure in the geology ot Wisconsin and Minnesota, is nonconformable upon the Animikie, and is a member of the fragmented beds of the Keweenawan. This has been named "Sioux quartzite," "Baraboo quartzite," and "New Ulm quartzite." It is that which contains the red pipestone (catlinite) in southwestern Minnesota. It is the western representative of the Potsdam sandstone, of Potsdam, N. Y. This quartzite seems to be the representative of the Middle Cambrian, as the Beckmantown is of the upper Cambrian.

9. The origin of the Mesabi iron ore is referred to a greensand, which has been altered, affording iron ore by concentration of the iron in certain favorable positions. Cotemporary with this alteration was a concentration of silica, and this was increased by oceanic precipitation. The original greensand was found to become pebbles, and to increase into angular masses that were neither sand nor pebbles, but rather breccia. These breccia masses have at first an amorphous crystalline texture and grade into a form of the iron-bearing rock which was named "taconyte," and the whole was referred to volcanic action, being different forms of suddenly cooled volcanic glass and rhyolite, broken and distributed by beach action. While this volcanic débris was undergoing this transformation, great quantities of silicia were set free from the glass; but this silicia immedially saturated the débris, producing spotted jasperoid, taconyte, and sedimentary jaspilyte.

Having reached this result on the Mesabi Range, it opened the door to the understanding of the iron ores of the Vermilion Range, and at once the rhyolitic forms and all the igneous associations of those ares with basic igneous rocks were elucidated, thus confirming Wadsworth's idea of the igneous origin of the jaspilytes of the Marquette region — rather the igneous origin of the rock which later was changed into jaspilyte.

10 and 11. After prolonged field examination, the Minnesota Survey reached the conclusion that the granites of the Archæan grade into gneiss, the gneiss into micaceous gneiss and mica schist, and finally into less and less metamorphic rocks that show a plain fragmental structure and sedimentary origin. There was found no exception among the Archæan granites. The granites are of two dates of formation — one at the close of the Lower Keewatin, and one at the close, or after the close, of the Upper Keewatin. A later granite, associated with the gabbro, and grading into it, is of the Keweenawan, and another did not spring from a deep source, but is a surface product of metamorphism carried to the extreme of fusion, on clastic materials that were later than the basal greenstones. Adventitiously they form intrusions in some of the later (and especially into the clastic) greenstones, but they are not known to penetrate the oldest greenstones. Tentatively the alkaline and the acid siliceous elements in these early sediments were supposed to have been derived from the atmosphere, as the basal crust could not have afforded them.

In the same manner the gabbro, which becomes acid and grades into syenite, was derivdd from the metamorphism and fusion of the greenstone with their clastic variations. Diabase was found to pass insensibly into gabbro; but, on the other hand, it is also certain that it was the original form of all igneous greenstones, and that it must have had, and still has, a deep-seated source.

These belts of intensest metamorphism, whether productive of granite or of gabbro, have a parallelism with each other, and with the northwestern rim of the great synclinorium of the basin of Lake Superior, marking successive continental folds, in harmony with a system which continued through Archæan and Taconic time, and even into the Upper Cambrian.

Comment.—Conclusions 5 and 6 are essentially in accord with conclusions reached by United States geologists who have worked in this area, although differing in nomenclature and minor points. The same may be said of Conclusion 7 in the matter of a greenstone being the oldest rock in the state, although Professor Winchell is alone in calling it the earliest crust of the globe. From Conclusions 8, 9, 10, and 11 the United States geologists dissent *in toto*. Adequate discussion of these conclusions would involve covering the entire range of Minnesota geology. The reader is referred to *Monographs XLIII*,[1] and *XLV*,[2] and to pp. 305–434[3] of Part III of the *Twenty-first Annual Report of the U. S. Geological Survey* for such a discussion.

N. H. WINCHELL. "Sketch of the Iron Ores of Minnesota," *American Geologist*, Vol. XXIX, pp. 154–62.

Winchell briefly describes the iron ores of Minnesota, and incidentally sketches their geological relations. No new points are added to those previously presented.

ROBERT BELL. "Report on the Geology of the Basin of Nottaway River." *Annual Report of the Geological Survey of Canada for 1900*, Vol. XIII, Part K, 1902.

Bell describes and maps the geology of the basin of the Nottaway River. Granites and gneisses referred to the Laurentian occupy the larger portion of the area. They are for the most part intrusive into the crystalline schists referred to the Huronian. Huronian rocks occur principally in a large area that is near the center of the region, and in small areas north of the center of the region and south of Lake Mistassini in the eastern part. The large tract of Huronian rocks forms a part of the great belt of Huronian rocks extending continuously from the eastern side of Lake Superior to Lake Mistassini, a distance of seven hundred miles. The Huronian may be grouped in three classes, namely: (1) crystalline schists, together with some other rocks forming a comparatively small proportion of the same series; (2) massive greenstones; and (3) granites. The schists embrace a considerable variety, but the greater part of them are dark green and hornblendic or dioritic, and they often pass into more or less massive greenstones, so that it becomes difficult to map the two varieties separately. Dolomite, quartzite, arkose, conglomerate, and agglomerate are exceptional occurrences.

J. BURR TYRRELL AND D. B. DOWLING. "Reports on the Northeastern Portion of the District of Saskatchewan and Adjacent parts of the Districts of Athabasca and Keewatin," *Annual Report of the Geological Survey of Canada for 1900*, Vol. XIII, Parts F and FF, 1902. With map.

Tyrrell and Dowling report on the northeastern portion of the district of Saskatchewan, and adjacent parts of the districts of Athabasca and Keewatin, comprising an area adjacent to the north end of Lake Winnipeg. The east, northeast, and northern

[1] C. K. LEITH, "The Mesabi Iron-Bearing District of Minnesota," *Monograph XLIII, U. S. Geological Survey*, 1903.

[2] J. MORGAN CLEMENTS, "The Vermilion Iron-Bearing District of Minnesota," *Monograph XLV, U. S. Geological Survey*, 1903.

[3] C. R. VAN HISE, The Iron Ore Deposits of the Lake Superior Region, *Twenty-first Annual Report of the U. S. Geological Survey*, Part III, pp. 305–434.

portions of the area mapped are occupied by Laurentian and Huronian rocks, of which the Laurentian rocks are in the larger areas. They consist of granites and gneisses, some of which are intrusive into the Huronian, and some of which are probably basal to it. Huronian rocks are found in small areas at Cross Lake, at Pipe Lake, and in the large area extending from Wekusko Lake to Athapapuskow Lake. They consist of conglomerates, quartzites, basic eruptives, and greenstones, and altered schists, similar to rocks of Lawson's Keewatin and Couchiching series.

A. P. Low. "Report on the Geology and Physical Character of the Nastapoka Islands, Hudson Bay," *Annual Report of the Geological Survey of Canada for 1900*, Vol. XIII, Part DD, 1903.

Low describes the geology of the Nastapoka Islands, Hudson Bay. The rocks forming the islands are in descending order as follows:

	Feet
1. Rusty-weathering, dark gray siliceous rock containing ankerite (carbonate of iron and magnesia, and magnetite	20–100
2. Dark gray siliceous rock containing magnetite, with small quantities of ankerite	50–250
3. Red jaspilyte rich in hematite ore	10-100
4. Red jaspilyte poor in hematite ore	5–20
5. Purple, or greenish-weathering, dark green, graywacke shales	10–70
6. Red jaspilyte poor in hematite ore	0–5
7. Light greenish-gray sandstone and shale	10–300
8. Fine-grained dolomite	0–50

There is a general dip toward the westward, or toward the sea, of from 5° to 15°. There are north-and-south faults, the upthrow being almost on the west side, with the result that the rocks appear in north-and-south ridges. The displacement is small and rarely exceeds one hundred feet. Another system of faults lies transverse to the first system.

Large areas of similar unaltered sedimentary rocks occur throughout the peninsula of Labrador, and are probably the equivalents of certain of the iron-bearing series about Lake Superior and of those to the westward of Hudson Bay, hand specimens from these localities being undistinguishable. On former maps of portions of the peninsula of Labrador, the areas of rocks belonging to this formation have been colored as belonging to the Cambrian formation, and in the earlier reports on this region the rocks were thought to be a part of that system, owing to their unaltered condition, in contrast with all the other rocks of that vast area that were either crystalline granites and other irrupted rocks, or crystalline schists and gneisses, so completely metamorphosed as to have lost all trace of their original sedimentary nature, if any were sediments. These highly crystalline rocks were classed as Laurentian or Huronian, and were considered to be much older than the unaltered rocks of the so-called Cambrian areas. More extended and closer study of both the unaltered and crystalline rocks, and of their relations to one another, has changed the views of the writer; and he now considers the unaltered, so-called Cambrian rocks to be the equivalents of many of the gneisses and schists classed as Laurentian (Grenville series), and the Huronian areas of the Labrador peninsula to represent a portion of the unaltered rocks and their associated basic eruptives (traps, trap-ash, etc.), altered by the irruption of granite and rendered schistose by pressure The granites which have been classed as typical Laurentian, always cut and alter the bedded rocks wherever seen in direct contact with them, and are consequently newer than the latter.

During the past season very thin layers of carbon with some resemblance to organic forms were found in the sandstones of Cotter Island; these have the appearance of lowly organized plant life, lower than the known fossils from the lowest beds of the Cambrian; and consequently this formation is older than the Cambrian. It is proposed, therefore to class these so-called Cambrian unaltered rocks as Laurentian, as they represent the oldest known sedimentary rocks in the northeast of America, and probably in the world.

West Virginia Geological Survey. Vol. I, Oil and Gas; Vol. II, Coal; and map showing the occurrence of coal, oil, and gas in West Virginia, By I. C. WHITE, State Geologist.

PROFESSOR I. C. WHITE, state geologist of West Virginia, has just issued a map showing the distribution of coal, oil, and gas areas in that state. The base of the map is topographic, with contours of 1,000 feet, and is, all in all, the most accurate map of the state which has ever been published. The map shows both the coal areas and the coal mines of the state. Of the former, the Pittsburg, the Allegheny-Kanawha, and the New River-Pocahontas are differentiated. In the aggregate, the coal areas cover nearly one-half of the state. The areas of natural gas and oil, though more restricted, are still extensive.

The map, just published, is a welcome supplement to the excellent volumes on Oil and Gas (Vol. I, issued in 1899), and Coal (Vol. II, issued in 1903). No state geological survey has issued economic reports of greater worth. While in the case of both volumes the treatment is primarily economic, the general structural relations of the Mississippian, Pennsylvanian, and Permian series, as developed in West Virginia, are clearly set forth.

R. D. S.

Geographic Influences in American History. By ALBERT PERRY BRIGHAM. The Chautauqua Press, 1903. Pp. x+366; 61 illustrations.

American History and its Geographic Conditions. By ELLEN CHURCHILL SEMPLE. Boston: Houghton, Mifflin & Co., 1903. Pp. 466; 16 maps.

THE above books are pioneers in a most interesting and important field, too long neglected. American history has been profoundly influenced by geological and geographical conditions. To ignore these controls is to make history very largely empirical. To recognize them is to go a long way toward making history a rational science. To

appreciate, for example, the geographic conditions which controlled every move of the contending armies of the Civil War in Virginia is to make intelligible a chapter of American history from which otherwise one gets but a confused, meaningless impression.

The scope of Professor Brigham's book is indicated by the chapter headings: "The Eastern Gateway of the United States;" "Shore-Line and Hilltop in New England;" "The Appalachian Barrier;" "The Great Lakes and American Commerce;" "The Prairie Country;" "Cotton, Rice, and Cane;" "The Civil War;" "Where Little Rain Falls;" "Mountain, Mine, and Forest." As these topics suggest, the author's view-point is always that of the geographer. The treatment of the subject is simple and somewhat popular, the book being designed primarily for a non-professional class of readers.

Miss Semple's book is a distinct contribution. The geographic influences which have shaped the trend of American history, from the discovery of the continent to the present, are treated in a scholarly and judicious manner. The inclusive character of the book is shown by the titles of the chapters: "The Atlantic States of Europe the Discoverers and Colonizers of America;" "The Rivers of North America in Early Exploration and Settlement;" "The Influence of the Appalachian Barrier upon Colonial History;" "The Westward Movement in Relation to the Physiographic Features of the Appalachian System;" "Geographical Environment of the Early Trans-Allegheny Settlements;" "The Louisiana Purchase in the Light of Geographic Conditions;" "Geography of the Atlantic Coast in Relation to the Development of American Sea Power;" "Geography of Sea and Land Operations in the War of 1812;" "Spread of Population in the Mississippi Valley as Affected by Geographic Conditions;" "Geographic Control of Expansion into the Far West: the Southern Routes;" "Expansion into the Far West by the Northern Trails;" "Growth of the United States to a Continental Power Geographically Determined;" "The Geography of the Inland Waterways;" "The Geography of the Civil War;" "Geographical Distribution of Immigration;" "Geographical Distribution of Cities and Industries;" "Geographical Distribution of Railroads;" "The United States in Relation to the American Mediterranean;" "The United States as a Pacific Ocean Power."

Miss Semple has been skilful in the selection of material from the great mass of scattered data. Irrelevant matters are invariably excluded, and the conclusions reached are generally fundamental. New light is

thrown on many topics. English success and French failure in North America are shown to have been largely due to geographic conditions. At the north the French followed every stream into the interior in quest of furs. "They spread themselves thin over an enormous area," and therefore failed. The Appalachian Barrier confined the English to the coast, and the many resulting advantages contributed to their success. It is popularly supposed that our possession of the Louisiana territory is due to a series of fortunate circumstances in European politics. Miss Semple shows that, once having passed the Appalachians, geographic conditions made it inevitable that the Americans should control the interior at least as far west as the Rockies.

The purchase of Louisiana was the occasion, not the cause, of the acquisition of the trans-Mississippi country. That must have come sooner or later. Even if the French had established themselves in Louisiana, they could not long have resisted the operation of geographic factors and the enterprising spirit of the western people, itself in part a product of environment. The trans-Mississippi region, hopelessly arid beyond the one-hundredth meridian, could never have supported a large enough population to resist the Americans, with whom the common navigation of the Mississippi would soon have brought them to blows. . . . . Had England conquered Louisiana from France — the chance which Napoleon feared — even her superior colonizing methods could not have made the country support a population large enough to cope with the thickly planted American settlements in the wide, rich, well-watered regions to the east. In a conflict between a cis-Mississippi and a trans-Mississippi power, the former had every geographical condition in its favor — coast-line, rivers, climate, soil, and habitable area. The Americans were destined to hold the West. The purchase hastened and facilitated the process.

The excellent discussion of the War of 1812 throws much light on a period which, to be understood, must be approached from the geographic side. Geographic conditions made this a frontier war and controlled all operations. The author does not overestimate the importance of the geographic view-point when she says:

The sea-fights of this war, if studied merely in their chronological sequence as presented in the ordinary school histories, leave only a confused impression, of which the student, young or old, retains little at all and less that is valuable. But an analysis of the geographical distribution of these engagements reveals a wide underlying system which explains their purpose and brings order out of an apparent chaos.

The Gadsden Purchase has been almost universally condemned as a purchase involving the payment of an enormous price for a small

tract of worthless land. Miss Semple maintains that because of the great strategic importance of the Gila River depression as a passway to the coast, money was never better spent.

Miss Semple believes the most potent factor in American expansion to have been the abundance of free land. The exhaustion of the supply has led to a recent exodus of westerners into Canada, over 50,000 going in the three years following 1899. It is pointed out that we must look to the recently initiated national system of irrigation in the arid West for the checking of this migration.

The arrangement of the matter in the book is not always the best, and a very few important topics are slighted. For instance, the discovery of gold in California does not receive due emphasis as a factor in American expansion. Such shortcomings are few, however, and the book is to be heartily commended to all students of geography and history.

H. H. B.

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—Clarke, John M. Construction of the Olean Rock Section. [Reprinted from Report of State Paleontologist, 1902; University of State of New York, Albany, 1903.]

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—Committee on Underground Temperature, Reports of the. Fifteenth, Sixteenth, Seventeenth, Eighteenth, Nineteenth, and Twenty-second Reports. [Neues Jahrbuch für Mineralogie, etc.]

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—Girardin, M. Paul. Rapport sur les observations glaciaires en Haute-Maurienne dans les Grandes-Rousses et l'Oisans dans l'été de 1902. [Commission Française des Glaciers, Paris, 1903.]

—Glenn, L. C. Devonic and Carbonic Formations of Southwestern New York. [Reprinted from Report of State Paleontologist, 1902; University of State of New York, Albany, 1903.]

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—Jefferson, Mark, S. W. Wind Effects. [Reprinted from Journal of Geography, Vol. III, No. 1; Chicago, January, 1904.]

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ICE-RETREAT IN GLACIAL LAKE NEPONSET AND IN SOUTHEASTERN MASSACHUSETTS.

INTRODUCTION.

LAKE NEPONSET is the name applied to the body of water which, during the final retreat of the Wisconsin ice-sheet, occupied the upper portions of the valley of the present Neponset River a few miles south of Boston. The existence of this lake was first pointed out by Professor W. O. Crosby, who regarded it as one of a series of more or less open lakes, the waters of which had gathered between the general ice-margin and the higher lands bordering the northward-sloping valleys in the region to the southwest, south and southeast of Boston during the period of retreat. The more important of the water bodies beginning at the west are designated by Professor Crosby as Lakes Sudbury, Charles, Neponset, and Bouvé. The deposits and history of Lake Bouvé have been discussed in detail by Dr. A. W. Grabau, while the Sudbury, Charles, and Neponset lakes have been defined and discussed in a more general way by Professor Crosby and Mr. F. G. Clapp.

In the writings of Crosby, Grabau, and Clapp,[1] the view, though not definitely stated, seems to have been tacitly accepted that, although there were doubtless many minor irregularities of the ice-front, the margin as a whole preserved a rather definite and regular terminal

[1] For MR. CLAPP'S present views see paper on "Relations of Gravel Deposits in the Northern Part of Glacial Lake Charles, Massachusetts," pp. 198–215 of the present number of the JOURNAL OF GEOLOGY.

facing, such as characterizes living glaciers. It was apparently conceived by the writers named that, as the face drew back to the north, a line of glacial lakelets came into existence at the heads of the northward-leading valleys. These, as the ice retreated, were considered to have grown in size and to have coalesced until the Sudbury, Charles, and Neponset lakes, and possibly also Lake Bouvé, became united into a single lake many miles in width and length, and of considerable area.

The studies of the present writer in Lake Neponset have led to the conclusion that the ice in that region, instead of retreating with a definite and somewhat regular front, had become absolutely stagnant before the history of the lake began, and that its disappearance was characterized by marked irregularities along lobes, deep re-entrants and detached blocks being the rule rather than the exception. Moreover, the marginal distribution of the deposits makes it seem probable, if not certain, that there was no general body of water such as was postulated for the Sudbury-Charles-Neponset stage, or even for the simple Neponset stage itself, but that the deposits, generally considered as marking the lake level or levels, were laid down in a series of small and more or less independent lakelets existing along the margins of the residual valley lobes or about entirely detached masses of ice.

In urging the improbability of the existence of large lakes with definite levels in this region during the earlier stages, however, the writer does not wish to be considered as denying the existence of considerable bodies of water in the lower portions of the valleys during the closing stages of the lakes when the ice-lobes and blocks had practically disappeared. In the following discussion of Lake Neponset the terms "lake" and "bay" are used to designate those portions of the basin of the Neponset River and its tributaries in which glacial sediments were laid down in standing water irrespective of time, elevation, or of the character of the water bodies in which the deposition took place.

Stoughton Bay is simply a portion of the Neponset basin, lying in the vicinity of the town of the same name. In this bay the conditions which the writer believes to have characterized the ice-retreat in the region under discussion are recorded very definitely in the

distribution and topographic expression of the deposits; and, as the history of the retreat in this locality is believed to be essentially the same as in the other glacial lakes of the region, the bay has, for the purpose of discussion, been selected as a type.

STOUGHTON BAY AREA AND ITS DEPOSITS.

Topography and drainage.—In a broad way it may be said that Stoughton Bay occupied a somewhat oval area surrounded by an interrupted belt of hills which, starting northwest of North Stoughton, extends southward about four miles, and then curves first to the west and then to the northwest, finally terminating in the range of hills southwest of Canton. The breadth of this basin is about four miles, and the length a trifle greater. The crests of the hills constituting the boundary vary from 200 up to 420 feet in altitude, while the intermediate cols vary from 190 to 250 feet in elevation.

Notwithstanding these relatively low gaps in the southern rim of the basin, it seems probable that the preglacial drainage, like that of the present period, was by way of the Neponset River to the north. Both the lower level of the rock-floors of the channels and the greater width of the valleys at the northern end of the area bear out this supposition. The possibility of a deflection of the drainage to the southwest through the valley now occupied by Massapoag Pond, has been considered, but although the valley is relatively broad, the frequent projection of rock "islands" through the outwash drift deposits, with which it is filled, appears to indicate that the rock bottom is much higher than in the present valley at Canton Village. The Canton valley, however, is not a broad one, the rock outcropping at relatively short distances from the stream on both sides, and probably underlying it at no great depth. The high elevation of the bottom of this channel, as compared with the low elevation, which probably characterizes the near-by Neponset valley bottom, would appear to indicate, either that the former is not the main preglacial drainage channel, or that the Neponset valley has been materially deepened by glacial erosion. The latter appears to be the more probable. In fact, the drainage and topography of even the bed-rock areas of this portion of Massachusetts show very few of the characteristics of normally developed drainage systems.

Relatively little is known as to the minor details of the rock topography within the basin, as the floor is deeply covered, except perhaps in the center, with extensive planes of stratified drift, which rises in places to nearly 150 feet above the marshy tracks along the main streams, which in turn are of unknown, though probably not very great, elevation above the rock-floors beneath them. The wells in the region are generally shallow, and in most instances afford little information of value. The details of the plains and of the cols in the rock-rim, many of which served as channels for the overflowing waters, can be considered to the best advantage in the discussion of the various stages in the history of the bed.

STAGES OF DEPOSITION.

The history of the Stoughton Bay area of Lake Neponset may be said to have begun when the first body of water came into existence between the ice and the retaining walls of the basin. Such a lakelet must of necessity have been of small size at the beginning, but soon became enlarged through the melting back of the ice. The outlets may have been over low points in the rock-rim, or along the edges of the ice. As the melting progressed, the expansion of the lakelets continued until the lower outlets of the waters were uncovered.

The different levels of the waters are indicated approximately by the altitude of the stratified deposits, which were laid down during the different stages. In Stoughton Bay these deposits are of two general levels, the higher standing at 250 feet, and the lower at about 190 or 200 feet above the level of the sea. The higher stage is named from the town of Stoughton, the greater part of which is located on the high-level deposits, while the lower stage is named from the village of Springdale, near which the lower planes are strongly developed.

The distribution of the materials show that not all the deposits, even of a single stage, were laid down in the same body of water, but accumulated, on the contrary, in more or less separate lakelets. The principal water bodies of the higher stage were the Rattlesnake Hill, East Sharon, and Stoughton lakelets, while the leading bodies of the lower stage were the Elm and Springdale lakelets.

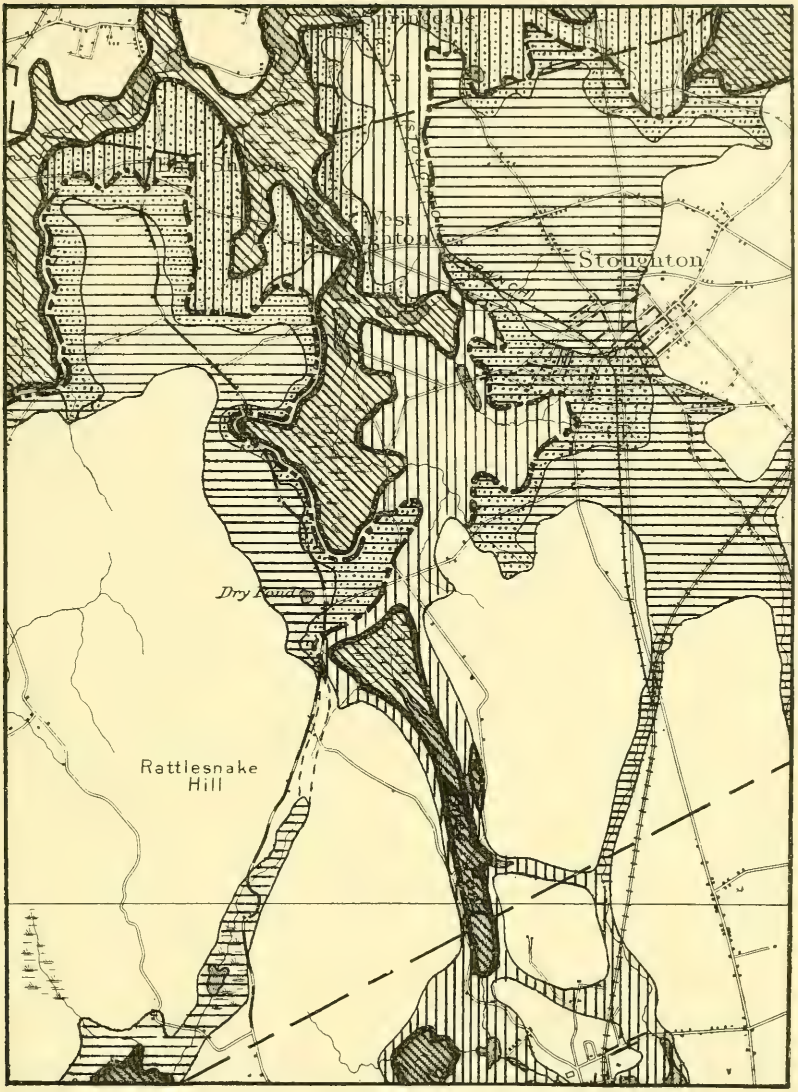

FIG. 1.—Retreatal Stages in Stoughton Bay of Glacial Lake Neponset.

Rock and till, generally higher than "high-level" plains.

High-level plains and outwash of East Sharon and Stoughton lakelets.

Gradation deposits between high- and low-level plains.

Low-level plains and outwash of Elm Street and West Stoughton lakelets

Gradation deposits below low-level plains.

Ice-masses at close of low-level stage of lakelets.

Position of ice-margin at opening of high-level stage.

Position of ice-margin at close of high-level stage.

Position of ice-margin at close of low-level stage.

EARLIER OR STOUGHTON STAGES.

Rattlesnake Hill lakelet.—This is the smallest of the recognized lakelets of the Stoughton Bay area, being less than half a mile in length and only about one-eighth of a mile in width. It was formed in a re-entrant just north of the col between Rattlesnake Hill, rising to 420 feet on the northwest, and another granitic hill, about 360 feet in height, on the southeast. The rock-floor of the col is not now exposed, but as there was free drainage to the south, the deposits though constituting a somewhat broad and flat sheet, are probably of slight thickness at the crest. The surface of these deposits stands at 250 A. T.

The deposits of the locality may be divided into three classes: (1) the outwash deposits in the channel leading southward from the

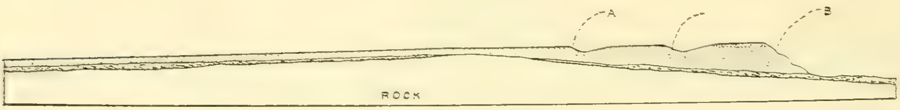

FIG. 2.—Diagrammatic north-south section through Rattlesnake Hill divide, showing outlet and broken delta deposits. (*A*, *B*, etc., show successive stages of ice-front during its recession.)

col; (2) the flat top deposits at and just north of the crest; and (3) the irregular and broken delta deposits on the north (Fig. 2).

The outwash gravels, which constitute a gentle sloping deposit extending down the valley to the southward, were evidently formed not later than the period when the ice-margin rested at the point represented by *A*, as the unfilled kettles and other depressions between the imperfect deltas to the north indicate that in the later stages little or no material was being carried into the lakelet.

The deposits at and just north of the crest consist of sands and fine gravels, and evidently represent the perfected lake deposits. They present an almost perfectly flat surface, one-eighth of a mile in width, and perhaps twice as long, which is so ill drained that in the wetter seasons the water stands over several acres, though of a depth of only a few inches. It is now the site of a cranberry bog. From this flat the rock hills rise with a sharp line of demarkation abruptly on each side.

At the time the deposits were laid down the ice probably presented a fairly definite face to the lake, the position being not far from the crest of the pass possibly near *A*. Later, however, the margin became broken up into detached blocks at its edge, the location of these blocks being represented by the imperfect planes and kettles lying just north of the crest. Continuing to the north, the deposits of stratified material end rather abruptly, the lower portions of the northward-leading valley, through which the ice drew back, being practically free from them. This would seem to indicate, either that the glacial streams had been diverted at some point farther north, or that they no longer carried any material quantities of sediments. Otherwise the deposits would have continued to accumulate in the lakelet which, in the later stages, must have reached some distance to the north of the deposits previously noted. The waters passing out from the lake to the south, being no longer overloaded with materials carried in suspension, began the work of eroding out the deposits laid down in the earlier stages, with the result that a thickness of ten feet of sand and gravel was removed throughout nearly the entire width of the valley leading south from the pass, the original level being represented only by an occasional terrace remnant standing about ten feet above the present valley floor. Imbedded in the silt, which here constitutes the floor, is a granitic bowlder, nearly fifteen feet in diameter, probably stranded on the rock or till surface underlying the silts during the melting of the ice and surrounded by subsequent deposits of sand.

East Sharon lakelet.—This name is applied to the body of water which lay between the granitic hills, one and one-half miles south of East Sharon, and the ice-front after the latter had shrunk back from the valley sides. The lakelet had a total length of approximately two and one-half miles. The greatest extent of open water was south of East Sharon (southwest of West Stoughton), where the lake measured a mile or more across. A mile southwest of West Stoughton the lake became contracted into what must have been simply a rather broad and sluggish lateral stream, which, however, opened up again to the southward into a marginal body, one-quarter of a mile or more in width, which continued to the north base of Rattlesnake Hill.

In this compound lakelet the deposits of the East Sharon stage

were laid down by the superglacial streams from the surrounding ice. The sand and gravel plains are most perfectly developed along the hillsides, as the lakelet was there shallowest and soonest free from ice. In such situations the plains were frequently built up to a horizontal upper surface, coinciding approximately with the water level, and are generally free from kettles. As the ice receded, lower portions of the hillsides were uncovered, and the water became deeper. The ice, however, melted back most rapidly along the surface of the lakelet, leaving projecting edges beneath the water, which became covered with sands and gravels. On the further melting of the ice and its disappearance from beneath these gravels, the materials were let down into irregular accumulations along the sloping valley sides, constituting the gradational deposits between the upper and lower plains, and between the lower plains and the present valley floor in the Stoughton Bay area. When the ice-wedge was very thin, gentle and fairly regular slopes resulted when the materials were let down, but when thicker, steeper and kettle-pitted slopes resulted. Dry Pond, in the southern part of East Sharon, is an example of such a kettle. This is the explanation of the change from a flat to a gently sloping plain, and finally to the irregular hummocky slopes which characterize the plains at many points in this area. The steeper ice-contact slopes, which are especially well developed in portions of the east side of the East Sharon plain, were formed where the marginal ice-wedge was only slightly developed. That the slopes of the plains cannot be regarded as purely depositional is shown by the fact that the inclination of the surface is opposite that exhibited by delta plains.

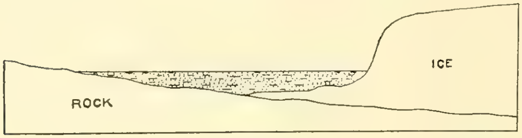

Fig. 3.

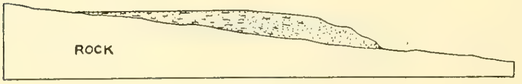

Fig. 4.

Figs. 3 and 4.—Showing mode of formation of gradational deposits: 3, marginal deposits before recession of ice; 4, plain and gradation deposits after recession of ice.

There can be no question that the materials of the plains came from the ice. This is attested by the rounding of the pebbles, the

lack of agreement in composition between the gravels and the adjacent rocks or tills from which they must otherwise have been derived, and the absence of even the most local postglacial deposits of similar character in the region.

The lake-level was regulated by the altitude of its outlet, which was through the notch southeast of Rattlesnake Hill, as in the case of the eariler lakelet of that name. The outlet stream was marginal as far south as the northeast base of the hill, but there the waters passed onto the ice, on which they continued until the notch was reached, as shown by the absence of erosional or depositional features in the intervening area.

That there was no outlet over the divide south of Massapoag Pond, which lies some two miles west of Rattlesnake Hill, is shown by the fact that the rock-floor is from ten to twenty feet or more lower than at the Rattlesnake Hill outlet, and as much below the level of the East Sharon and Stoughton Plains, the highest of which it could not, therefore, have controlled. The field evidence, moreover shows that the Massapoag valley was occupied by ice until a late stage in the history of the Stoughton Bay region.

Stoughton lakelet.—This is by far the largest of the lakelets in the Stoughton Bay region, and receives its name from the town of Stoughton which is located in the middle of its area. Like the East Sharon lakelet, it was compound, being composed of a larger water body at the north and a smaller one at the south, the two being apparently connected by a narrow channel along the eastern margin in the vicinity of Stoughton. Like the East Sharon lake, it was also located, at least so far as the northern or main portion is concerned, at the termination of a rock hill projecting between two converging valleys in which the ice still remained.

The breadth of the northern portion of the lake from north to south was about one and one-half miles, and from east to west about one and one-quarter miles. The southern portion of the lake was more irregular. From east to west it measured somewhat over a mile in length, but it was less than half a mile in width.

In the northern half of the lakelet the broad Stoughton plains were deposited. While in a general way these plains present a uniform upper limit, the plain was in many places never built up to a

perfectly smooth surface, but is characterized by broad, gentle undulations, merging into kettles about the margins. Some parts, however, are as flat as a floor. In the southern half of the lakelet the plains are generally quite broken, though occasional flat-topped areas exist. The margins of the plains nearest the valleys present in both areas the same gradational type as the East Sharon plains.

The natural outlet of the Stoughton lakelet would at first sight appear to have been southward along the valley followed by the railroad, or along the similar valley half a mile farther east. The altitude of these outlets in each instance, however, is less than 200 feet, while the flat tops of the sand plains, which probably indicate the approximate level of the water of the lake, is 250 feet, or the same as that of the Rattlesnake Hill and East Sharon deposits. It seems clear, therefore, that the southward valleys mentioned were still blocked by the ice. The elevations of the Stoughton plains, corresponding as they do with that of the Rattlesnake Hill outlet, suggest that it was through this notch that the water passed on to the south. To do this it must have crossed the tongue of ice still occupying the valley north of Ames Pond. An examination of the locality seems to show beyond reasonable doubt that this was in fact the case, the waters crossing just north of the road leading eastward from near Dry Pond. The waters in passing deposited much material on the ice, which, on the melting of the latter, was left as an irregular belt of sands, gravels, etc., across the valley at the point indicated, and practically connecting the Stoughton with the East Sharon plains.

LATER OR SPRINGDALE STAGES.

Elm Street lakelet.—This lakelet came into existence after the ice-margin had melted back to a point a mile or more to the west of the position it occupied during the deposition of the Stoughton plains. The lakelet proper was about three-quarters of a mile wide from north to south, and a mile from east to west. In it was deposited the typical flat-topped plains traversed by Elm and Water Streets about a mile southwest of Stoughton. Its upper surface stands at an elevation of 210 feet, and the plain is bounded on the northeast, north, and west by sharp ice-contact slopes, while on the east and south it slopes off into rolling deposits, apparently quite distinct from

ordinary fore-set slopes, and probably representing deposits along the subaqueous ice-wedge, afterward let down as irregular gradational masses, as explained in the case of the East Sharon plains.

The altitudes of the upper limit of the flat-top deposits indicates that the Rattlesnake Hill outlet had been abandoned, and that a newer and lower outlet to the south had been opened up through the valley occupied by Ames Pond at a level of about 210 feet. The ice had not entirely left the valley, a narrow tongue still remaining in the center, along both sides of which, as indicated by terraces with ice-contact slopes toward the valley, outflows took place. On the west side the water followed straight through the valley, but on the east side a portion passed off to the eastward by sub-outlets through notches located respectively near where the highway crosses the pond and just above the south end of the pond.

West Stoughton lakelet.—The West Stoughton lakelet was a body of water one and one-half miles long and one-half a mile wide, extending from Springdale on the north to a point about a mile west of Stoughton on the south. The plain which now marks its position, though fairly flat in places, is much more broken than most of the other plains described, presenting in many places rolling and kettle topography characteristic of deposition open and around more or less detached sheets or blocks of ice. Fine ice-contact slopes extend all the way around the edge from West Stoughton to Springdale, marking the margin of the ice, still occupying the center of the valley.

The elevation of the surface of the West Stoughton plains is from 190 to 200 feet. It seems to have been formed at a slightly later period than the Elm Street plain. The lower altitude of its surface is probably due to the fact that the ice in the depression now occupied by Ames Pond (artificial) had finally disappeared, opening up an outlet a few feet lower than that existing at the time the Elm Street plain was formed. The surplus waters probably escaped through the main and two sub-outlets in the vicinity of Ames Pond as in the case of the Elm Street plain.

Closing stages.—Within the limits of the Stoughton Bay area there are no records of Lake Neponset later than the stage marked by the deposition of the low level plains just described, unless certain unimportant irregular deposits occurring in the center of the valley

are regarded as marking the final passing away of the ice. The ice already reduced to a mere line along the center of the valley could have remained but a short time, and, as the later outlets appear to have been to the north, no further stages of the lake are recorded.

RETREATAL CONDITIONS.

Absence of ice-movement.—That ice-movement had ceased before the opening of the lake history of the Stoughton Bay area is clear from the character and distribution of the deposits laid down. Nowhere in the region are there any deposits of the nature of moraines, such as would have been formed at the front of a living ice-sheet. This applies both to the uplands and to the valleys, which are alike free from till accumulations formed either along a general ice-front or at the terminations of valley ice-tongues.

The form and structure of the stratified deposits also fail to show any forward movement of the ice-bodies, along the margins of which they were laid down. Folding and faulting of a nature indicating thrusts are absent in all exposures which have been seen, and the ice-contact slopes are practically free from till accumulations, such as would have been formed if the ice had possessed sufficient motion to bring fresh materials to the front. The topographic forms are always those which would result from a receding ice-margin, never from an advancing one. The gradational deposits described on pp. 185, 186 are especially significant in this connection.

The strongest evidence, however, is from the distribution of the deposits, which, as has been described, form relatively narrow and successive strips along the sides of the valleys, showing conclusively, when examined as a whole, that the ice-shrinkage was not from south to north, or any other fixed direction, but always away from the valley sides. At the latest recorded stage, as shown by the surrounding deposits, only a narrow strip of ice remained along the center (Fig. 1). Neither this nor the earlier and wider masses possessed the straight or gently curving outlines characteristic of living ice-tongues, but were marked by all the sinuosities and irregularities of an irregularly melting stagnant ice-margin.

Drainage of the ice-sheet.—The highest stratified deposits of Stoughton Bay are the Rattlesnake Hill, East Sharon, and Stoughton

plains, which were deposited in standing water at an altitude of 250 feet. These plains have an aggregate area of at least five square miles, and a probable average thickness of 75 feet. Certain reasons have already been given (pp. 183, 184) why these deposits cannot be regarded as derived from the surrounding uplands, but the most conclusive argument is their immense bulk, considered in connection with the absence of erosion features on the surrounding uplands. That the material came from the ice, therefore, there can be no doubt. The question then is: Were they deposited by subglacial or by superglacial streams?

Half a mile southeast of East Sharon the plains, which here consist of sands and of gravels with pebbles up to several inches in diameter, stand at an altitude of 245 feet, or over 100 feet above the valleys on the east, north, and west, across which the materials must have been borne. If the gravels were transported by subglacial streams, they must have been suddenly lifted a distance of 100 feet. To move a pebble 2 inches in diameter along a level bottom requires a current with a velocity of 2.8 feet per second; to lift it upward requires a velocity of about 3 feet per second. This would correspond to an upward pressure along the assumed ice-tunnel across the valley to the north of 43 pounds to the square inch, and to indicate a head of 2 feet per mile in a straight conduit like that of a circular pipe 6 feet in diameter. In a conduit with the many irregularities of a glacial tunnel the head would probably have to be 10 per cent. greater, or approximately 3¼ feet per mile, in order to give the observed velocity. Slightly lower figures would be given by larger conduits. Such a head could be found at a distance of many miles to the northwest. In living glaciers subglacial streams may possibly exist for considerable periods of time, but it seems beyond the ground of probability that a subglacial stream, with the pressure indicated, could continue over hill and valley for long distances beneath the stagnant ice-sheet without finding a passage for the more ready escape of its waters.

The temperature of a subglacial stream is always, according to observations, slightly above the freezing-point. The corrosive action of a stream, with the velocity and pressure indicated, would rapidly eat the roof of its tunnel, until during a somewhat extended period,

such as would be required for the upbuilding of extensive plains like those of the Stoughton Bay area, a base-level was reached. In crossing a valley the roof of the tunnel would be at least as high as the median height of the valley walls on the up-stream and down-stream sides. The motion of the water would be mainly superficial, and the lower or slack-water portion of the tunnel in the valley or depression would become filled to grade with deposits, which would eventually be left as an immense esker. No deposits of such a character occur in connection with the plains in this region.

In case of the plains of the Stoughton Bay area, there can be no doubt that the streams supplying the material were englacial or superglacial. Of the two, superglacial streams are the more probable. It is clear that there was a connection across the ice between the Stoughton and East Sharon plains, while the waters from both flowed a short distance over the ice in their passage through the Rattlesnake Hill outlet. If superglacial drainage existed at one point, it is likely to have existed at several, and, in the absence of all evidences of subglacial drainage, can reasonably be accepted as the predominant type. It is not assumed that subglacial drainage was not common in other regions, nor that it did not exist to some extent in the region now under discussion; but it played little or no part in the upbuilding of the plains.

Inception of lakelets.—In an earlier paragraph it has been pointed out that there is every reason to believe that the ice had become stagnant before the first of the lakelets of the Stoughton Bay area came into existence, and it is probable that all movement had ceased while the entire surface of the region was still covered by the ice. As the melting of this stagnant ice-field went on, the hilltops began to appear, and the superglacial drainage was obliged to seek the notches for outlets. Seemingly, the first pass to be uncovered was the one immediately west of Rattlesnake Hill, at an altitude of approximately 325 feet; but it appears to have been so situated that it was not available to any of the superglacial streams, for an examination of the ground shows that there was no outflow of water through this pass. Following this, the next to be laid bare as the melting progressed must have been the notch immediately east of Rattlesnake Hill, at an altitude of 250 feet. This is the outlet which is known as the Rattlesnake Hill outlet.

Lakelets of the earlier stages.—The position of the ice-front at the beginning of the flow through the outlet was very near the crest of the pass, as indicated by the distribution of the plains. Later, however, the ice drew back slightly, while farther north it receded at the same time from the valley walls sufficiently to bring into existence the East Sharon lakelet on the west side of the valley and the Stoughton lakelet on the east. Ice-masses still occupied the Massapoag and Ames Pond valleys, and the two southward-leading valleys southeast of Stoughton, leaving the Rattlesnake Hill notch as the only available passage to the south. The outlets of both lakelets were through this pass, to reach which the drainage of both, as has been explained, passed over the ice itself for a short distance.

Opening of the Ames Pond outlet.—The earlier or high-level stages of the Stoughton Bay lakelets were brought to a close when, by the shrinking away of the ice from the retaining hillsides, lower outlets were opened through the valley of Ames Pond. This valley is marked on both sides by terraces exhibiting ice-contact faces on the sides nearest the pond, constituting, in fact, true kame or morainal terraces—a feature not often recognized in eastern Massachusetts. From these it is evident that an ice-tongue still remained in the middle of the valley. This was at first possibly connected with the larger remnant of the ice farther north in the valley, but the melting of the ice, which had previously proceeded slowly by ordinary surface ablation, now probably went on with much greater rapidity, owing to the action of running water on both sides of the valley mass. This rapidly cut away the ice, already greatly reduced by the stream crossing from the Stoughton to the East Sharon lakelet, with the result that the Ames Pond mass was early separated into an independent block.

Lakelets of the later stages.—The Elm Street lakelet was the first of the lower-level bodies to be formed, and the waters found outlet along both sides of the Ames Pond block, forming the kame terrace deposits mentioned. The waters in part passed out from the valley by a bowlder-strewn gorge through granite ledges at the head of the bay just southeast of the highway across the pond, in part by the wider, sand-filled valley between rock hills just above the lower end of the pond, and in part directly southward along the main valley.

Following the Elm Street, the West Stoughton lakelet was formed. By this time the Ames Pond block had become much contracted, or had entirely disappeared, affording an outlet, from 10 to 20 feet lower than the earlier, through the valley now occupied by the pond. These later waters carried little sand, and are represented, therefore, not by deposits, but by their erosive action. The faces of the terraces of the valleys were shaped in places by these waters, but in the main they are of the nature of ice-contact slopes.

CONCLUSIONS.

The results of the study of the Stoughton Bay area, in so far as they apply to retreatal conditions, prove: (1) that in this area the ice had become stagnant before the inception of the lakelets, and remained so throughout their history; (2) that the ice, previous to the emergence of the hills through its surface, was reduced almost entirely by superficial ablation; (3) that the subsequent melting was most rapid along the margins of the projecting land masses, because of the radiation of heat from them and the concentration of drainage along their borders; and (4) that the shrinkage continued to be outward in all directions from the exposed land masses, until the ice was reduced to narrow lines along the deeper valleys, and finally disappeared essentially simultaneously from all portions of the area.

APPLICATIONS.

Extent of glacial lakes.—Hitherto, in the discussion of glacial lakes in eastern Massachusetts, as was pointed out in the introduction, it has been assumed that the ice retreated with a rather definite and regular margin, in front of which extensive bodies of water accumulated in the northward-sloping valleys. While the observations of the writer have not been sufficiently extended to discuss in detail the conditions in other lakes, it has appeared almost certain from reconnaissance studies that the size of the open water bodies in the various lakes at any given time were much smaller than has usually been supposed, and that the marginal lakelets were very numerous, and definite and regular margins relatively rare, the ice having disappeared, in many instances, in the same manner as in the Stoughton area. Which type of retreat prevailed can be determined

only by careful field work, though the facts now at hand seem to indicate that the mode of retreat discussed in the present paper is the most common.

Conditions in southeastern Massachusetts.—A study of the numerous, and often very large, kettle depressions in the stratified drift plains south of Middleboro, and at various other points in Plymouth county in southeastern Massachusetts, shows that throughout large areas in this part of the state extensive masses of stagnant ice existed during the final disappearance of the ice. How broad a belt of such ice existed at any one time or place cannot be readily determined, but in general the belt of no motion was probably not over ten or twenty miles in width, as more or less indefinite morainal bands indicating active ice-movements are found at intervals across the area, while occasionally more pronounced deposits occur.

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RELATIONS OF GRAVEL DEPOSITS IN THE NORTHERN PART OF GLACIAL LAKE CHARLES, MASSACHUSETTS.

INTRODUCTION.

Among the most impressive features of the glacial deposits in eastern Massachusetts is the great abundance of sandplains, which occur by scores in all the large valleys. The characteristic flat surfaces, lobate fronts, steep or kettled ice-contact slopes, and tributary eskers testify to the formation of the plains as deltas in glacial lakes, through transportation of the sand and gravel from the ice in which it was incorporated by powerful glacial streams flowing either upon or beneath the ice, and deposition in standing water along the glacier front. In association with the true sandplains are areas of kames, eskers, and other irregular deposits varying from mere patches of gravel to tracts several square miles in extent. At intervals during a period of two or three years the writer has had opportunity to study in detail the sands and gravels within a certain limited area, and takes this opportunity to give a few of his results, hoping they may throw some additional light upon the glacial-lacustrine history of the region.

LAKE CHARLES.

Lake Charles is the name given to the lake, or series of lakelets, which occupied the valley of the Charles River during the decay of the latest or Wisconsin ice-sheet.[1] The region drained by the river embraces portions of the counties of Suffolk, Norfolk, Worcester, and Middlesex, and is covered by the Boston, Framingham, Dedham, Franklin, and Blackstone topographic sheets. All portions of the valley are crowded by thick deposits of sand and gravel, among which flat sandplains are conspicuous, wave-cut shore lines have been occasionally noted, and on the east and south sides of the basin a num-

[1] W. O. Crosby and A. W. Grabau, *American Geologist*, Vol. XVII (1896), No. 2, pp. 128–30; F. G. Clapp, "Geological History of the Charles River," *Technological Quarterly*, Vol. XIV (1901), No. 3, pp. 171–201; No. 4, pp. 255–69; and *American Geologist*, Vol. XXIX (1902), pp. 218–33.

ber of well-defined lake outlets are known, each of which, as a rule, corresponds in level with the upper surfaces of a particular series of plains. Moreover, a study of the individual plains shows that a number of them often reach approximately to a common elevation, and, with few exceptions, they may be classified into one of several groups distinguished by their different levels. The elevations of the most abundant of these—not including those near sea-level—have been found to be approximately 150, 170, 200, and 270 feet in elevation, although local groups and isolated plains occasionally occur at intermediate levels. A fact thought to be of considerable significance is that plains having a common elevation are distributed over very wide areas. Deltas of the 170-foot series not only are known north and south of the Dover highlands and in the adjacent Neponset valley, but are very abundant across the divide of the Sudbury River in the vicinity of Cochituate, and even far down the valleys of the Sudbury and Concord Rivers. The widespread distribution of plains of the same general elevation at first appears to indicate the presence in the region of a large open body of water, which with successive retreats of the ice-margin, opening outlets for the lake at consecutive lower levels, allowed the water to fall repeatedly to the next stage below. Recent studies by Mr. M. L. Fuller in the Neponset basin indicate, however, that in that region there was no such simple sequence of events; and the present writer, working independently, finds evidence in Lake Charles indicating that here too the open lake hypothesis can be accepted only in part.

DESCRIPTION OF THE REGION.

The location of the main region under consideration in the present paper is shown in Fig. 1. In a general way, it includes that portion of the Charles River basin lying south of the Boston & Albany Railroad in Newton and north of the Dedham and Dover highlands. More definitely, it is that part of the drainage basin of the present Charles River lying within that of the preglacial Charles. The portions of the valley lying north of the Boston & Albany Railroad, and those east of the Brookline and West Roxbury highlands, are not included, being within the limits of what has been designated Lake Shawmut—a glacial lake corresponding with later stages of the ice-retreat.

Topography.—A glance at the topographic map shows that the region may conveniently be divided into the following subdivisions: the Western highlands, the Dover and Dedham highlands, the Brookline and West Roxbury highlands, the Needham-Waltham valley,

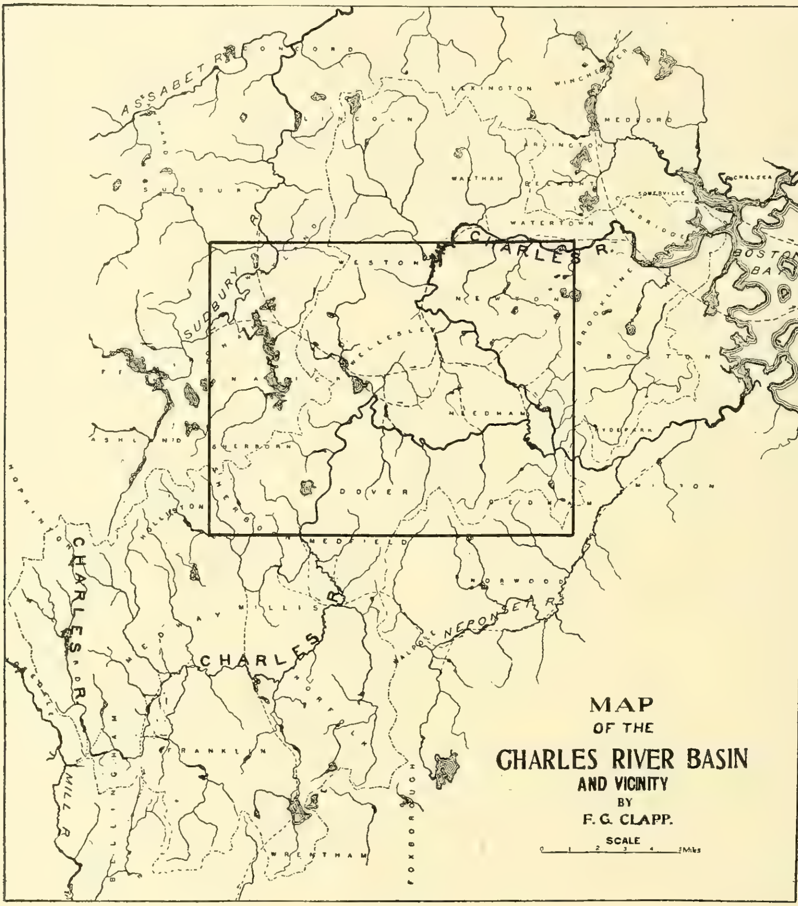

FIG. 1.

and the regions intermediate between uplands and lowlands, the last division consisting of the greater part of the towns of Newton, Needham, and Wellesley. Another feature of importance is the broad area of modified drift extending westward from Wellesley to the Sudbury River, and overlying the site of a broad preglacial

valley 100 feet or more below the present surface. This valley—the ancient outlet for the Sudbury valley drainage, is supposed to continue beneath Wellesley to the valley of Rosemary Brook, and thence northward to the present Charles River at Riverside. The broad marshy area east of Needham, in which the bed-rock surface is known to lie at a considerable depth below sea-level, was probably occupied by a tributary of the Charles which entered the main river just north of Highlandville. The valley between South Natick and Dedham contained no single preglacial stream. The largest unbroken upland region is the broad band extending westward from the Neponset River across Dedham, Westwood, Dover, and Sherborn, which in preglacial times separated the lowlands on the north and south into two distinct drainage systems, since united along the course of the Charles River.

DESCRIPTION OF THE DEPOSITS.

In a provisional classification we may recognize the following types of deposits as occurring in this portion of Lake Charles:

1. Flat-topped delta-fans—typical gravel plains—the level of which varies but a few feet in a single plain. These deltas almost invariably have a beautiful ice-contact slope, but the common lobate front may or may not be developed. For this class of deposits the common name of "sandplain" is used, although the plains considered consist largely of gravel.

2. Kettle plains, or deposits with a definite maximum elevation, but so broken up by kettle-holes as to have little semblance to plains. In origin, they differ from true sandplains only in having been formed among crowded ice-masses.

3. Eskers, or deposits of glacial streams. These are often conspicuously tributary to deltas.

4. Irregular deposits of gravel along the sides of valleys, usually consisting of great numbers of small hills or kames densely crowded together, for which the name "moraine-terrace" is sometimes used.

5. Kames—the name comprising all small, irregular hills of sand and gravel not included under (3) or (4).

6. Thin coatings or undulating deposits of gravel, apparently having no definite relations.

In the present study particular attention is given to the first three types.

SANDPLAINS.

Although in ascertaining the elevations of the plains the writer has not had opportunity to do any leveling, yet from the excellent contouring on the new Boston sheet, and in some instances by the aid of the older topographic maps, the approximate elevations have been interpreted in the field. Within the immediate area under consideration twenty-five typical plains have been studied, which are here named, with their approximate heights above tide. The distribution of the plains and their associated eskers is shown in Fig. 2.

1. Newtonville plain, 150 feet.
2. Newton Highlands plain, 150 feet.
3. Newton Center plain, 150 feet.
4. Winchester Hill plain, 150 feet.
5. Nahantan plain, 150 feet.
6. Cow Island plain, 140 feet.
7. West Roxbury plain, 140 feet.
8. Dedham Island plain, 150 feet.
9. Lower Falls plain, 150 feet.
10. Waban plain, 150 feet.
11. Wellesley plain, 150 feet.
12. Needham plain, 170 feet.
13. Birds Hill plain, 190 feet.
14. Dedham plain, 120 feet.
15. Wigwam plain, 120 feet.
16. Islington plain, 120 feet.
17. Pegan plain, 160 feet.
18. Noanet plain, 150 feet.
19. Cedar Hill plain, 270 feet.
20. South Natick plain, 120 feet.
21. Trout Brook plain, 100 feet.
22. Greendale plain, 100 feet.
23. Riverside plain, 60 feet.
24. Auburndale plain, 70 feet.
25. Newtonville plain No. 2, 80 feet.

Where the plains slope appreciably away from the ice-contact the elevation of the outer edge is taken, as representing most closely the true water-level. Most of them slope slightly, the difference in elevation sometimes amounting to as much as 20 feet, which makes it evident that plains having elevations given as 150 feet and others as 170 feet might have been formed as deltas in the same body of water. That such was probably *not* the case will be shown below.

In addition to the plains already enumerated, several exceptionally fine developments outside the Needham area have been visited in this connection. The most important of these are as follows:

26. North Wellesley plain, 170 feet.
27. Pickerel Pond plain, 170 feet.
28. Cochituate plain, 170 feet.
29. South Framingham plain, 170 feet.
30. Medfield Junction plain, 170 feet.

A comparison of the elevations of the thirty deltas shows that twelve of the number have an elevation of 140–50 feet, six of them of

170 feet, four of 120 feet, three of 60–80 feet, two of 100 feet, one of 160 feet, one of 190 feet, and one of 270 feet. All below 120 feet were deposited during the Lake Shawmut stages. The remaining twenty-five will be described somewhat in detail.

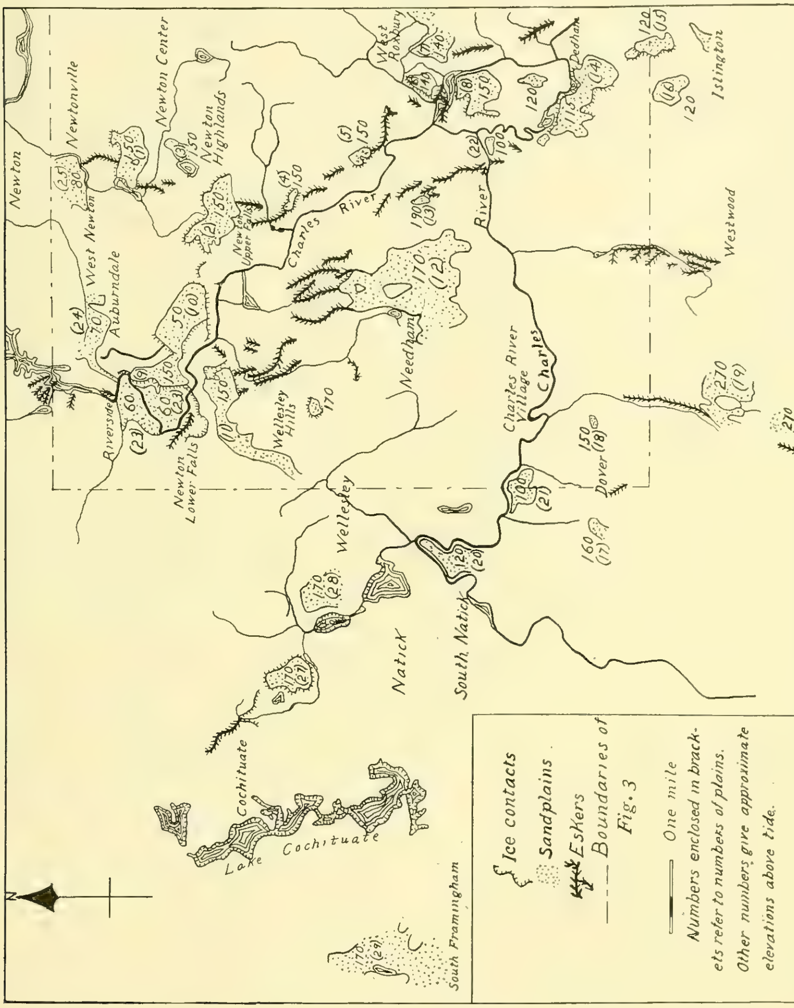

Fig. 2.—Distribution of principal eskers and sandplains. The dash line shows the boundary of Fig. 3.

NEWTONVILLE-WEST ROXBURY SANDPLAIN ESKER SYSTEM.

This series of deposits is situated entirely on the east side of the Charles River, and consists of a continuous series of alternating plains and eskers extending from the northern end of the Newtonville

esker, one-half mile south of the Boston & Albany Railroad, across Newton to the frontal lobes of the Dedham Island and West Roxbury sandplains—a total distance of about six miles.

Newtonville esker and plain.—The classical delta known as the Newtonville sand plain, which has been described by Davis and Gulliver,[1] lies fully a mile south of the railroad, about half-way between Newtonville and Newton Center. It has an elevation of 150 feet, and averages fully three-fourths of a mile long and half a mile wide, occupying nearly the whole breadth of the valley of Laundry Brook. Several preglacial knobs rise through the plain, and to the east it rests against a low rock hill capped by a drumlin rising to an elevation of over 300 feet; on the north and west sides are characteristic ice-contact slopes; while a short stretch on the south forms good frontal lobes. Viewed from any standpoint, the deposit is a typical sand-delta, and well merits even more careful study than it has received. A large excavation on Commonwealth Avenue gives an unexcelled opportunity for viewing its internal structure.

The feeding stream of the delta is represented by the Newtonville esker, which first appears as it rises from beneath the lower and more recent plain at Newtonville, about three-fourths of a mile north of its junction with the sand plain. On both sides are large areas of densely crowded kames and kettles, with which the esker in places becomes somewhat confused.

Southwest of the plain there is also a small kame area. Unlike the southeast side, which has good frontal slopes, the southwest corner immediately south of Commonwealth Avenue breaks up into kames and kettles, which are composed of very coarse gravel, abounding in bowlders up to several feet in diameter. Within four hundred feet a further change takes place, by which the irregular hills become shaped into a typical esker, bounded on both sides by kames, and running in the direction of the Newton Highlands plain. Before reaching this there is a short break, due to a swamp, but the parallelism of the esker to the rock hill on the east, the close similarity between the levels of the two plains, and the apparently perfect

[1] W. M. Davis, "The Subglacial Origin of Certain Eskers," *Proc. B. S. N. H.* Vol. XXV (1892), pp. 477–99; F. P. Gulliver, "The Newtonville Sand Plain," Journal of Geology, Vol. I (1893), pp. 803–12.

topographic relationship indicate strongly that the esker stream was the feeder of the Newton Highlands delta.

Newton Highlands plain.—This plain, somewhat irregular in shape, extends a little over a mile in an east-and-west direction, and half a mile in its greatest breadth north and south. Like the Newtonville plain, it is bounded on the east by a rock hill, has ice-contact slopes on the north and northwest, and frontal lobes on the south; but the ice-contact in this case differs in character from the other by being extremely irregular, and in places much broken up by kettles. On the southwest the fore-sets run against the rock hill south of Eliot Station; on the north and south it is bounded mainly by low, swampy areas. It is for the most part a typical sandplain.

Cook Street esker.—The most interesting feature of the Newton Highlands plain is on the south side, near the Cook Street junction of the New York, New Haven & Hartford with the Boston & Albany Railroad. At this point a small knob of conglomerate rises above the glacial drift, and towards the north and east the fore-sets are broken and irregular, indicating the presence of ice here at the time of their deposition. Directly east of the conglomerate knob and south of Cook Street is a low esker running southward out of the sandplain. Beyond the first road it rises to a height of 30 feet or more above the swamp, and farther south widens to a breadth of at least 500 feet; but within 2,000 feet ends abruptly at a small brook. As this somewhat peculiar esker has been extensively excavated, its internal structure can be easily studied. The south end being in itself something of a delta, the main stream which formed it was probably not *directly* tributary to any plain.

Winchester Hill eskers and plain.—A few hundred feet to the west, however, and holding very definite relations to the small plain west of Winchester Hill, is another esker. Starting half-way up the side of the rock hill south of Eliot Station, it descends fully 40 feet. becoming at once a good-sized ridge, crosses the swamp to the kame field west of Highland Avenue, with which it soon becomes confused, and joins the sandplain at its northwest corner.

The Winchester Hill plain is comparatively small, hardly one-eighth the size of the Newtonville plain, although topographically its relations are somewhat similar; it is bounded on the east by a drumlin,

the remaining three sides being free. Unlike the deltas already described, this plain has no frontal lobes, being surrounded on the north, west, and south by ice-contacts. Both to the south and west are extensive areas of kames and moraine-terrace.

Nahantan plain.—Lying a mile and a half southeast of Winchester Hill, in the midst of a large kame field, is a plain having the same approximate maximum elevation as the surrounding kames and of the associated esker. In extent of isolation it goes a step beyond the Winchester plain, as its surface does not rest at any point against rock or till, and it is entirely surrounded by ice-contacts and kames. As the slope of the Brookline highlands is not over 1,000 feet distant, it is likely that rock exists only a short distance below the surface, and the plain occupies as truly a marginal position as the others mentioned. In the area between this and the Winchester plain are two eskers, which, while they have not been observed to run directly into either plain, are supposed from their positions to mark the streams which carried the water southward between the two lakelets.

The esker running out of the Nahantan plain is better defined in its relations than the ridges similarly situated with reference to the preceding deposits. It quickly attains its individuality, and borders the kame area for nearly half a mile before finally disappearing below the Charles River meadows. One feature well worthy of special note occurs just south of the plain, where there is an enlargement of the esker barely 200 feet across, yet having all the characteristic structural features of the larger plains. South of the terminus of this esker the relations of the eskers of the series are not well defined. Short ridges appear above the flood-plain west and north of Cow Island, and continue from near Spring Street southeastward, crossing Washington Street on the boundary line between Boston and Dedham, beyond which no attempt has been made to trace them. At the southern point of Cow Island is a good junction of the main esker with a ridge which crosses the river from the south.

Cow Island, West Roxbury, and Dedham Island plains.—The elevations of the first two of these are indicated by the map as about 10 feet lower than the other plains of the system. This discrepancy may be real, but is more probably due to difficulty of interpreting the contours on a map of the published scale. In either case, it is believed

that these three plains are of the same height, and were controlled by the level of a single body of water. They are all bounded on the west by steep and irregular ice-contacts, and the West Roxbury and Dedham Island plains rest visibly against preglacial knobs of land. With the Cow Island plain, on the contrary, no till nor rock can be found associated, and several wells drilled at the pumping station on the southeast side of Cow Island prove that the drift is here very thick. In one instance 90 feet of gravel was penetrated before reaching bed-rock.

Conclusions and discussion.—From the foregoing description several characteristics common to the deposits may be formulated:

1. The plains are nearly always marginal—deposited about knobs of rock or till. Conversely, most of the preglacial prominences rising above the valley floor have glacial deposits associated with them. This is probably partly due to the natural sinking of the decaying ice masses into the valleys, and in part to the principle that the heat reflected from rock masses accelerates the melting of the ice immediately surrounding them, forming hundreds of small marginal lakelets, throughout the decaying zone of the ice-sheet.

2. The plains without exception have a definite ice-contact slope, which in several instances entirely surrounds them, except on the sides which are bounded by higher land. This feature indicates that some of the lakelets became entirely filled by gravel, forcing further deposits to accumulate in quantity along the channels of glacial streams or in superglacial lakelets.

3. Where typically developed, the deltas are associated with feeding eskers on the north, and with effluent eskers on the south. Such a relation can only mean that the glacial lakes, like bodies of water on the present land surface, had both inflowing and outflowing streams, the latter carrying off the surplus water and providing a transporting and depositing agent for the excess of gravel. This is in accordance with what has been observed on the Malaspina glacier.[1] The controversy in regard to the superglacial or subglacial origin of eskers will not be entered here, but the writer believes there is evidence that eskers of both classes exist in the region, and that

[1] I. C. RUSSELL, "Expedition to Mt. St. Elias, Alaska," *National Geographical Magazine*, Vol. III, pp. 106–8.

by careful study of the individual cases their differences in origin can be detected.

4. The elevation of all the plains of the system is very nearly or quite uniform, at about 150 feet above tide. Thus, notwithstanding the supposition that there can have been no large open lake in the region, there was certainly some connection between the lakelets adequate to maintain the water at a common level. The remnants of the decaying ice-sheet consisted of stagnant valley-blocks much broken up, the whole mass saturated with water, which was maintained at a uniform level consequent on some factor outside the Needham area. Into this basin were discharged torrents of water, which carried the gravels and deposited them upon, beneath, and between the ice-masses. This view is satisfied both by the superglacial and subglacial theories of eskers, and further corroborates the supposition that in this area there are examples of both classes.

As the difference in elevation between the different plains of the series can not be more than a few feet, it is evident that in the waters of the lakelets themselves or below their level there can have been but little current. Notwithstanding this, it is known that water-worn bowlders of considerable size are abundant in many of the eskers and associated deposits, indicating a very powerful current. The most probable explanation, already alluded to, is that to the main superglacial or subglacial rivers were tributary many side streams which discharged into them from higher levels on the ice or surrounding land. The extensive kames and moraine-terraces are best explained, as shown by Fuller in the case of Lake Neponset, by supposing them to have been deposited upon masses of ice sometimes of considerable thickness, having a front sloping outward beneath the lacustrine waters.

The probable conditions existing during this stage are indicated in Fig. 3, in which the lakelets are represented by the dotted portions and the stagnant remnants of the ice-sheet by shading. The regions covered by a combination of these patterns usually correspond in position with large areas of moraine-terrace, and were at this time ice-tongues overlain by considerable depths of water, in which the superglacial and subglacial gravels were deposited. Glacial streams, so far as traceable, are shown by heavy black lines.

Their most striking feature is that they are conspicuously divided into two series, one following in a general way each side of the main valley and known to have connected with the other only at a single

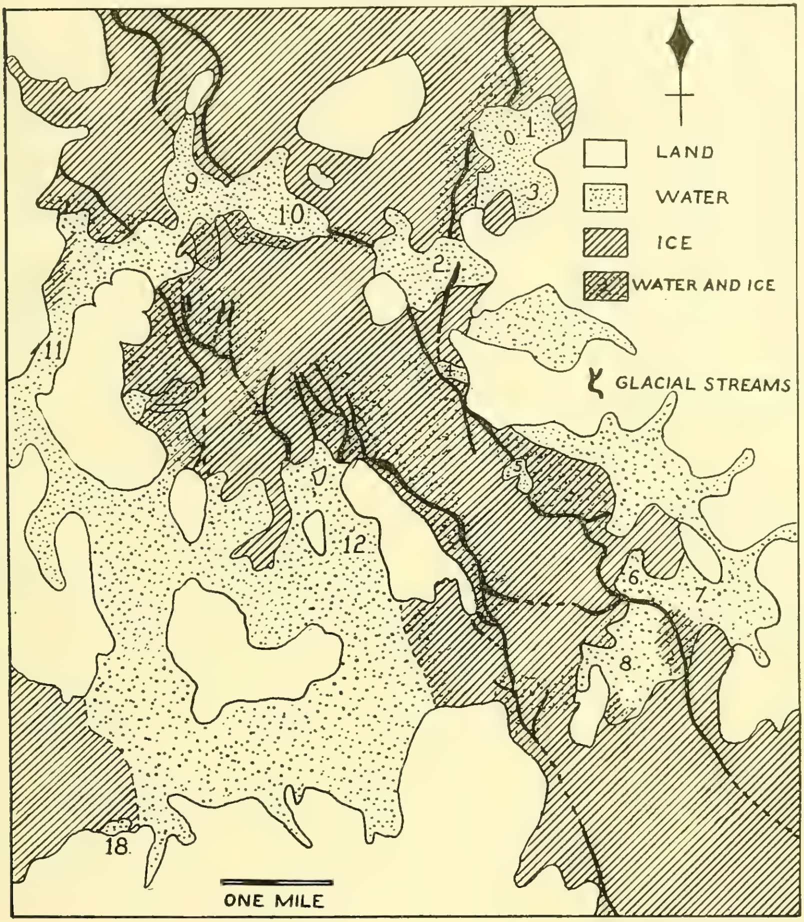

FIG. 3.—Probable conditions during the 140–170-foot stage of the glacial lakelets. (Numbers show locations of plains, and correspond with list given in the text.)

point. It is probable, however, that there were other connections which have not been preserved in the deposits. A second noticeable feature in the eastern series is the confluence at the Winchester Hill lakelet of two rivers, both of which have been traced for some dis-

tance outside the map, and were apparently the only main streams draining the triangular area which they include.

THE NEEDHAM-FRAMINGHAM SYSTEM OF PLAINS.

For convenience of discussion this designation is applied to the group of plains lying between Needham and Framingham, having, in addition to a common elevation of approximately 170 feet, most of the characteristics of the preceding group. These deposits cover an area beside which the Newtonville-West Roxbury area appears insignificant; yet, as the writer has had little opportunity to study them in detail, they will be dismissed with a few remarks. Belonging to the group are at least six plains—the Framingham, Cochituate, Pickerel Pond, North Wellesley, and Needham plains. All have good ice-contact slopes, most of them on certain sides only; but one plain, that lying east of Pickerel Pond between Wellesley and Cochituate, is entirely surrounded by characteristic steep and kettled slopes. This plain, like that forming Cow Island, is the only member of its group not resting against the rock sides of the valley, and, like Cow Island, is supposed to overlie a buried preglacial gorge.

The most conspicuous topographic characteristic of this region is the abundance of kettle-holes, often occupied by ponds. Lake Cochituate, Dudley, Pickerel, Mud, Jennings', and Morse's ponds and Lake Waban are all kettle-ponds, overlying the course of the preglacial Charles River. Between, around, and upon the ice-blocks gravels were deposited, their mode of origin being demonstrated by their kettled character. The proportionate area of kames to kettles is much larger than in the deposits farther east, and the kettles are more isolated. Plains having in general the same elevation extend far down the valleys of the Sudbury and Concord Rivers; thus emphasizing the suggestion that in the Sudbury valley there were at that time fairly open bodies of water.

Needham plain.—This is the largest and most typical plain in the group. Hemmed in on east and west by rock hills, it is bounded on the north by a deep preglacial valley, in which the ice lingered and gave rise to deep kettles, extensive moraine-terraces, kames, and eskers. Three or more eskers, with relations suggesting a superglacial mode of origin, enter the plain from the north. Its southern

side shows a beautiful lobate front, which, together with the absence of kettles and the scarcity of modified drift immediately to the south, indicates that in that direction was an open lakelet three to four miles in extent. The overflowing water, reinforced by the drainage from an extensive area to the west, found its outlet eastward through a large superglacial or marginal stream.

Lower Falls, Wellesley Hills, and Waban plains.—These are all about 150 feet in elevation, and the first two originally formed a single plain. Extending in an irregular line from near Rice Crossing north of Wellesley Hills to Newton Lower Falls, and thence to the high morainic hills east of Riverside, is a kettled and kamey ice-contact nearly three miles in length. Large kettles south and east of the Lower Falls indicate that the glacier to the north was almost connected with the decaying ice-blocks on the southeast side of the plain; but that it was not quite continuous is indicated by consideration of the fact that the slopes on both sides of the river are erosion slopes, in which artificial excavations show nearly horizontal stratification, probably once continuous across the valley. The Waban plain, lying closely adjacent to the Lower Falls plain on the east, was formed by the Auburndale esker stream.[1] It is bounded on the north and south by ice-contacts, is much broken up by kettle-holes, and might properly have been classified with the Newtonville-West Roxbury group, with which it is closely connected.

Other plains of the series.—In the valleys east and west of Dover are two or more small plains at approximately the same elevation, which are shown by ice-contacts on their valley sides to be deposits of small marginal embayments. Plains of the Newtonville-West Roxbury type occur in the Medfield-Medway basin of the Charles River, and also in the Neponset valley. The uniformity of elevation over such a wide area strongly suggests dependence upon some lake-outlet east of the Neponset valley. No systematic search for such an eastern outlet has been made in the field, but it is known that in the southern watersheds of the Charles and Neponset Rivers there is no pass lower than 200 feet above tide.

[1] J. B. Woodworth, "Some Typical Eskers of Southern New England," *Proceedings of the Boston Society of Natural History*, Vol. XXVI, pp. 197–220; W. M. Davis, "The Subglacial Origin of Certain Eskers," *ibid.*, Vol. XXV, pp. 477–99.

The perfect ice-contact slope along the Boston & Albany Railroad east of Wellesley Hills, together with the absence of any flat-topped deposits rising higher than 90 feet, throughout the area to the northward, and likewise from the entire region east of the Brookline and West Roxbury highlands, proves that the northern part of the Boston basin was then occupied by the still little-decayed ice-sheet, an arm of which extended up the Neponset valley as far as Norwood.

PLAINS OF OTHER LEVELS.

Cedar Hill lakelet.—There still remain to be mentioned several important plains at levels different from any heretofore described. One of these plains occurs on the divide between Noanet and Mine Brooks in Dover. It lies at an elevation of 270 feet, and has a tributary esker on the north and frontal slopes on the south. Beginning a short distance south of the plain, and extending to beyond Walpole, a distance of over four miles, is one of the finest eskers in the region, supposed to mark the course of the stream through which this lakelet discharged.

Dedham plains.—In the towns of Dedham and Westwood are several plains having an elevation of about 120 feet. These are flat-topped, are either entirely or nearly surrounded by ice-contacts, have abundant kettles, and are not known to correspond with plains of any other group. Along the valley of the Charles River, between Dedham and South Natick, are a number of plains at elevations of 100 to 120 feet, which may belong to the same stage. Below this elevation all the plains are confined to the Lake Shawmut area, the western limit of which is marked by flat 90-foot deposits north of the ice-contact at Riverside and Newton Lower Falls, and which extend eastward throughout the Boston basin, where they are recognized at all elevations down to sea-level.

HISTORY OF THE LAKELETS.

The highest known plain in the region, the Cedar Hill plain, has an elevation of 100 feet above the next lower level, and must have been formed at the time of the earliest uncovering of the pass in the Dover highlands, which left a lake irregular in shape covering an area of nearly one square mile, walled on the east and west by rocky hills, and on the north and south largely by ice. The eskers in the

valleys of Noanet and Mine Brooks suggest that this is another instance of a glacial lake having both inflowing and outflowing streams.

The occurrence of so numerous and widely scattered sandplains having a uniform elevation, which, notwithstanding their wide distribution, were evidently formed in merely local lakelets, often resting in part on the ice itself, is best explained by the assumption that the ice was in such a state of decay as to allow a connection between the individual lakelets sufficient to maintain the water at a common level. Such being the case, the general level of the waters at the different stages must have been determined by one of two causes; either, first, by deposition in an arm of the sea, or, second, as was more probable, by topographic features, probably passes between the highlands on the east side of the lower Neponset valley, through which the water escaped to Lake Bouvé,[1] and thence to the sea. The probable explanation for the lack of plains between the 270- and 170-foot levels is the absence of any pass intermediate between these elevations on the northern side of the Blue Hill range. In the southern portion of Lakes Charles and Neponset, where passes of other levels occur, intermediate plains also abound. The relations of ice, land, and water during the 170–150 foot stage are shown in Fig. 2.

This stage of the lakelets existed during the entire time while the outlets remained at this elevation. When the decay of the ice had advanced sufficiently to open a 120-foot outlet north of the Blue Hills, the ponded waters fell to that level. There is no indication that during this time there was any considerable disappearance of the ice in the upper and central portions of the Charles River basin, for in these portions no plains are known below 160 feet. The absence of synchronous plains in the Lake Shawmut area indicates that this was still for the most part ice. By far the greater portion of the 120-foot plains is situated in the town of Dedham, their location being probably due to their favorable position at the head of the Charles River valley glacier. Another view of their origin is that they represent merely a local stage, while the greater portion of the waters stood at a lower level.

[1] A. W. Grabau, "Lake Bouvé," *Occ. Papers, Boston Society of Natural History*, Vol. IV, part III, pp. 564–600.

CONCLUSIONS.

The most important generalizations to be drawn from this study are as follows:

1. The decay of the ice *in situ* for many miles back from the ice-front—the decaying glacier consisting of a mass of stagnant ice overlain and buried by sheets of water and by extensive deposits of sand and gravel.

2. The more rapid disappearance of the ice on the west than farther east, causing a nearly open lake in parts of the Sudbury valley, while as yet the ice in the lower portions of the Boston basin had not decayed sufficiently to allow the formation of a single sand plain.

3. The interdependence of the water levels of the individual lakelets belonging to each stage, and their correspondence with some common outlet toward the sea.

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WASHINGTON, D. C.

THE LEOPARDITE (QUARTZ PORPHYRY) OF NORTH CAROLINA.[1]

INTRODUCTORY STATEMENT.

WHILE engaged, during the past summer, in a study of the granites of North Carolina for the State Survey, opportunity offered for examination in the field of the well-known and interesting rock called "leopardite," which occurs near Charlotte in Mecklenburg county. Knowledge of the occurrence of this rock in the state dates back many years, and brief descriptions of it have been published from time to time by different writers, as noted below in the appended references.

In 1853 Dr. Hunter[2] briefly described, megascopically, the general appearance, including locality, of the leopardite found near Charlotte, Mecklenburg county, North Carolina. He says: "It is noticed by Professor Shepard, under the head of feldspar, as the leopard stone of Charlotte, North Carolina." Professor Shepard regarded it as composed of compact feldspar and quartz spotted by the oxides of iron and manganese. Hunter suggested the propriety of retaining the name "leopardite," for the reason that it is quite characteristic of a rather unique rock. In the same paper the author refers to a second locality in Lincoln county, North Carolina, where leopardite had recently been found. Concerning the character of the rock in Lincoln county, he says: "The pervading stripes are, however, generally finer; and when broken diagonally, it presents a handsome arborescent appearance."

In 1862 Dr. F. A. Genth[3] described the leopardite occurring near Charlotte as a true porphyry, and gave some general results of a microscopical examination of thin sections of the rock, including a chemical analysis. Still a third locality in North Carolina where

[1] Published by permission of the state geologist of North Carolina.

[2] C. L. HUNTER, "Notices of the Rarer Minerals and New Localities in Western North Carolina," *American Journal of Science.*, Vol. XV (1853, 2d ser.), p. 377.

[3] F. A. GENTH, "Contributions to Mineralogy," *ibid.*, Vol. XXXIII (1862, 2d ser.), pp. 197, 198.

leopardite is reported to be found is referred to by Genth, namely, near the Steele mine in Montgomery county.

More recently the leopardite occurring near Charlotte has been noted by Merrill[1] and Lewis[2]. After briefly describing the general appearance of the rock, Professor Merrill makes further statement of its economic value. In connection with his work on the building-stones of North Carolina, Lewis visited the locality to the east of Charlotte, where the leopardite is exposed, and, so far as contained in published accounts of the rock known to me, he was the first to note its true geological occurrence.

Quartz porphyries in association with other closely similar acid volcanic rocks are developed, in places, over the central and the northwestern parts of the state. So far as known at present, the areas of acid volcanic rocks are confined to the volcanic belt which skirts the western margin of the Triassic sandstone in the eastern Piedmont region,[3] and to several of the extreme northwest counties[4] of the state. These rocks show no essential differences, so far as they have been studied, from certain areas of similar ones which occur and are traced at irregular intervals northward along the Atlantic border region of North America as far as Newfoundland.

Of those occurrences in North Carolina, the quartz porphyry found near Charlotte is the only one visited by me that shows the characteristic spotted appearance so suggestive of the name "leopardite." Except for the mottled or spotted appearance produced by rounded black areas of metallic oxides, the Charlotte rock differs but slightly, if at all, in essential characters from quartz porphyries described from other localities. (See table of analyses on p. 223).

[1] George P. Merrill, *Stones for Building and Decoration* (New York, 1897), 2d ed., pp. 272, 273.

[2] J. V. Lewis, *Notes on Building and Ornamental Stone,* First Biennial Report of the State Geologist, N. C. Geological Survey, 1893, p. 102.

[3] George H. Williams, "The Distribution of Ancient Volcanic Rocks Along the Eastern Border of North America," Journal of Geology, Vol. II (1894), pp. 1–32; J. S. Diller, "Origin of Paleotrochis," *American Journal of Science*, Vol. VII (1899, 4th ser.), pp. 337–42.

[4] A. Keith, *Bulletin No. 168*, U. S. Geological Survey, p. 52; *Geologic Atlas of the United States*, "North Carolina-Tennessee, Cranberry Folio," 1903.

LOCATION AND OCCURRENCE.

The leopardite is exposed in a number of small outcrops at Belmont Springs, about one and a half miles east of Charlotte. Beginning on top of the hill, several hundred yards above the spring the rock is traced in outcrops over the surface for a distance of a quarter to a half mile in a north 30° east direction. It forms a true dike, intersecting a medium textured and colored, sheared and crushed,

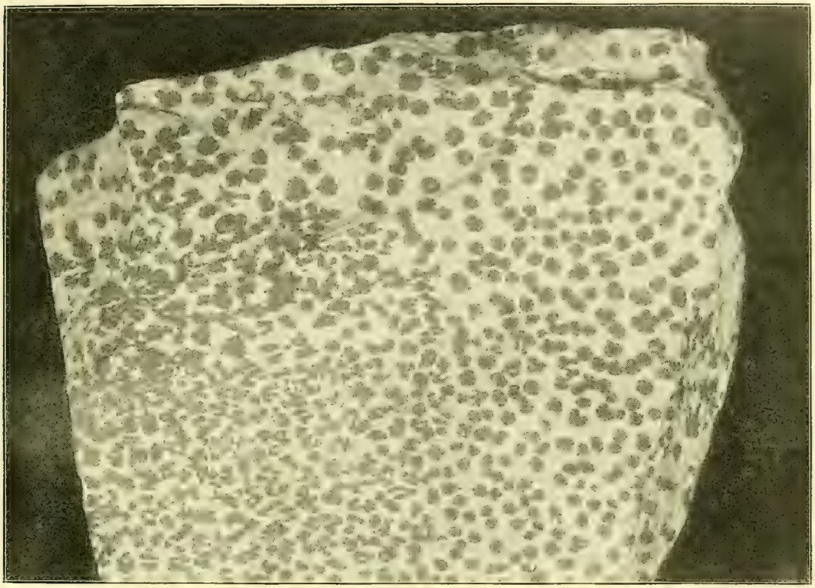

FIG. 1.—View showing the spotted appearance of the rock on a surface broken at right angles to the longer direction of the pencils. Photographed from a hand specimen. (One-half natural size.)

biotite granite; and, so far, as it was possible to determine, the dike nowhere exceeds twenty-five feet in width, with a smaller average cross-section. A small opening in one of the outcrops from which some of the rock has been blasted reveals a sharp contact between the quartz porphyry and the inclosing granite.

MEGASCOPIC DESCRIPTION.

The fresh rock is nearly white, tinged the faintest greenish in places, and penetrated by long parallel streaks or pencils of a dead

black color. When broken at an angle to the direction of the pencils, the rock surface appears spotted with rounded, irregular black points, ranging in size up to a half inch in diameter. At times the roundish points are somewhat irregular and only partially developed, as shown in the lower left half of Fig. 1. These may be crowded close together over the surface, as seen in the figure, or or they may be entirely absent from some areas and irregularly distributed at wide intervals over others, as indicated in Fig. 3. Indeed, the black points are reported to fail entirely in the rock as the dike is traced northward, when the rock assumes a uniformly light color throughout. However, every outcrop and specimen of the rock seen by me contained them.

A section cut parallel to the direction of the pencils presents a surface streaked with long, somewhat irregular, though roughly parallel, black lines, more or less perfect dendritic or fern-like forms (Figs. 2 and 3). I was shown recently a large slab of the rock collected from one of the outcrops since my examination in the summer of 1903, which, for perfection and delicacy of tracery in fern-like forms, was beautiful beyond description. The black streaks or pencils which characterize the rock are composed of a staining of the oxides of manganese and iron.

The rock is cryptocrystalline in texture, breaking with a conchodial fracture, and is intensely hard and tough. Minute quartz crystals of doubly terminated pyramidal faces are distributed through the rock at irregular wide intervals. These are nowhere abundant in the rock, but they are always present to some extent, and consist both of the light-colored and the dark, smoky, vitreous quartz. Indeed, unless carefully examined, the rock would ordinarily be pronounced non-porphyritic in texture, so small and scattering are the porphyritically developed quartzes. Megascopically, porphyritic texture is nowhere particularly emphasized in the rock, but its slight development is best seen on a weathered surface of the stone, where the unaltered quartz crystals, though few in number and widely scattered, contrast more strongly with the weathered surface and appear more conspicuous than in the fresh rock. Feldspars are also porphyritically developed, as described below, though the phenocrysts are difficult of differentiation in hand specimens of the rock.

MICROSCOPICAL DESCRIPTION.

In thin sections the rock consists of a holocrystalline groundmass and scattered small porphyritic crystals. Flow-structure is not exhibited in the groundmass, and the phenocrysts indicate no orientation with respect to each other. The groundmass is micro-granitic in structure, though some sections show much of the micro-granophyric structure, with an irregular radial, spherulitic, structure developed in greater or

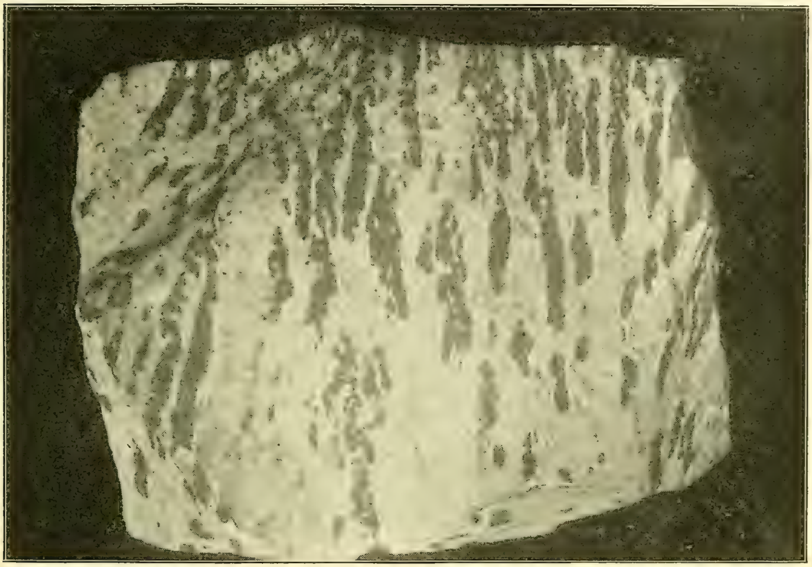

FIG. 2.—View showing approximately parallel black streaks and pencils on rock surface broken parallel to the direction of the pencils. Photographed from hand specimen. (One-half natural size.)

less proportion in all of the sections studied. When they form complete spheres, which is rarely the case, they usually exhibit somewhat irregular ragged peripheries, and further show usually between cross nicols a very indefinite black cross. The form of the grains in the typical micro-granitic areas of the groundmass is sharp and allotriomorphic to partially idiomorphic. The principal groundmass minerals are feldspar and quartz, with much light-colored mica, and an occasional inclusion of prismatic apatite and zircon. Irregular minute grains of iron oxide are scattered through the sections, and stained

areas from manganese and iron oxides, forming the dark spots and pencils in the hand specimens, occur. The thin sections are characterized by the complete absence of ferro-magnesian minerals.

Feldspar is apparently in largest quantity, and is composed of both potash and plagioclase species. Occasional grains of microcline are recognized which show the characteristic microcline twinning. The unstriated feldspar grains so strongly resemble quartz that it is impossible in many cases to distinguish them without the application of optical tests. Optical tests show the plagioclase to be albite—a circumstance entirely confirmed by the chemical analysis of the rock given below in the table of analyses under I, in which only the barest trace of lime is indicated, with soda in large amount and in excess of the potash. Some of the plagioclase exhibits polysynthetic twinning according to the albite law, and at times assumes lath-shaped forms. The feldspar substance is generally fresh, but the individual grains are usually rendered dark by abundant, closely crowded, minute, dark, dust-like particles, the identity of which could not be made out.

Quartz is of the usual kind and presents no noteworthy features, further than its occurrence in small mosaics of interlocking grains, which occupy at times distinct areas in some of the thin sections.

Light-colored mica, tinged a faint yellow, is very generally distributed through the sections, in the form of irregular minute shreds, groups, and aggregated masses, the folia of which are at times imperfectly arranged radially about a common center. A part, at least, of the mica is clearly secondary, while some of it is yet doubtful as to origin, whether primary or secondary. Its general appearance and association in the sections might very well indicate secondary formation for all of it.

Phenocrysts of both quartz and feldspar occur in well-developed idiomorphic forms, usually in rectangular and squarish cross-sections. In the thin sections studied phenocrysts of feldspar are more abundant than quartz; and while the porphyritic texture is poorly developed in the hand specimens, it is very pronounced in the thin sections. The quartz phenocrysts show irregular fractures free from impurities, strained shadows, and occasionally inclose grains of feldspar. The porphyritic feldspars show in part broadly twinned bands of plagio-

clase, and untwinned orthoclase. These are frequently rendered nearly opaque from innumerable, closely crowded, dark inclusions not identifiable, along with minute spangles of colorless mica. Zonal structure is rarely observed, and cleavage is usually wanting. Around the borders of several of the feldspar phenocrysts slight embayments, produced by incipient resorption, are noticeable.

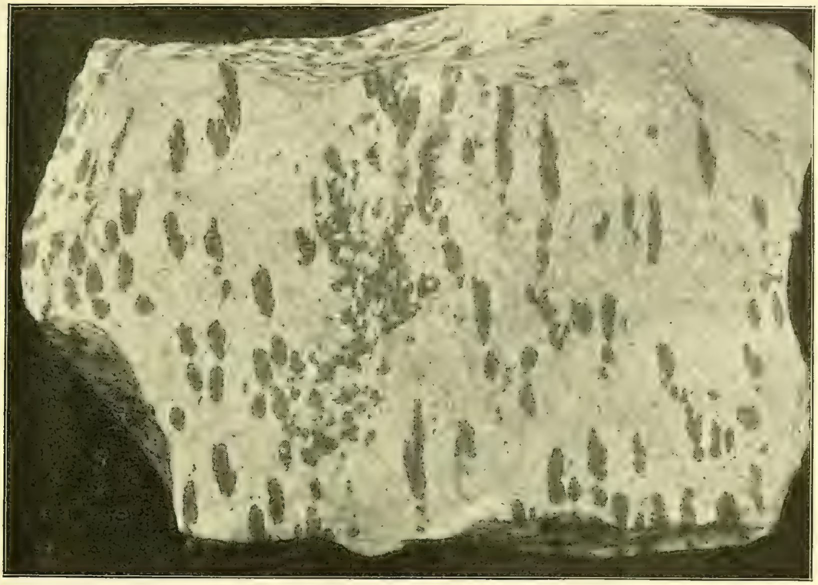

FIG. 3.—View showing partially spotted and partially streaked rock, with tendency toward arborescent form manifested near the middle of the picture. Surface broken at an angle intermediate between that of Figs. 1 and 2. Photographed from hand specimen. One-half natural size.

Several of the sections were so cut as to include areas of the black pencils which characterize the rock, megascopically. These are distinguished, microscopically, from the white portions of the groundmass only by a distinct medium-to-dark yellowish-brown staining, somewhat resembling that of limonite stain frequently observed discoloring tiny areas of the rock, derived from the partial leaching of any iron-bearing constituent in igneous rocks. No definite source of the staining was entirely indicated in any of the sections, but the areas clearly represent percolation of solutions of manganese and iron

salts through the rock. Why the definite arrangement into long pencils and dendritic forms manifested megascopically, evidence is again lacking, for the textural relations of the minerals in the discolored areas are precisely the same microscopically, as for other portions of the rock. The character of the staining suggests that the spotted and streaked appearance of the rock is a superficial phenomenon, and perhaps does not extend to any very great depth.

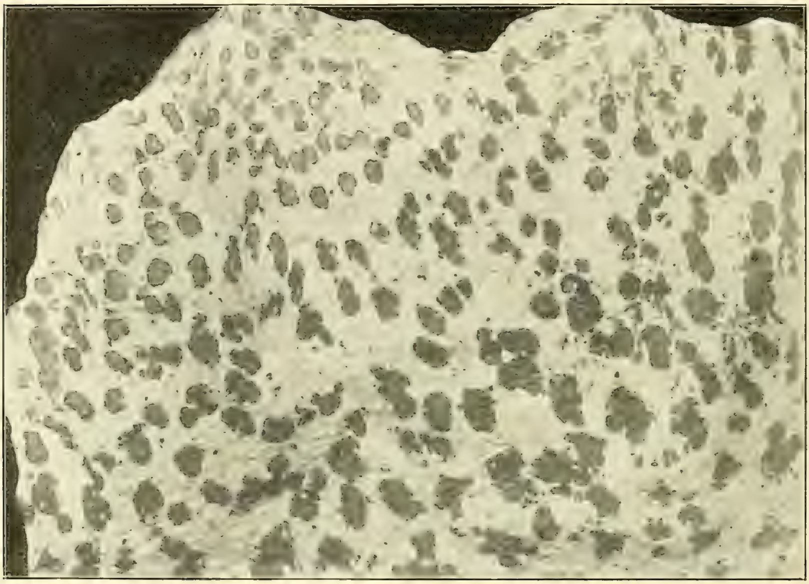

Fig. 4.—View showing weathered surface of the rock. Partial leaching of the dark spots is emphasized in the upper portion of the picture. Photographed from hand specimen. (One-half natural size.)

CHEMICAL COMPOSITION.

The chemical composition of the rock is given in analysis I of the table of analyses. The analysis of leopardite was made by Dr. F. A. Genth from the freshest fragments of the groundmass obtainable. The most striking features of the analysis are (1) the very acid character of the rock, as manifested in the high SiO_2 content; (2) the nearly complete absence of CaO and MgO; and (3) the increased Na_2O which is in excess of the K_2O. The analysis, however, har-

monizes closely with the microscopic study of thin sections of the rock, for the absence of ferromagnesian minerals accounts for the very slight amount of MgO present, while the practical absence of CaO and the large percentage of Na_2O prove the plagioclase to be albite, as indicated above by the microscope.

This analysis is compared in the table with a recent, more detailed one (II), of a quartz porphyry occurring in the northwestern part of the state, and with a spherulitic rhyolite (III) found east of the Charlotte locality in Montgomery county; and with analyses IV and V of well-known quartz porphyries occurring in other parts of the United States. A perusal of the figures given in the table will make clear the general similarity of the rocks, notwithstanding the rather striking differences indicated in some of the constituents.

TABLE OF ANALYSES.

	I	II	III	IV	V
SiO_2	75.92	79.75	79.57	73.12	72.85
Al_2O_3	14.47	10.47	11.41	14.27	13.78
Fe_2O_3	0.88	0.64	0.20	0.51	1.87
FeO	....	0.92	0.70	0.26	0.36
MgO	0.09	0.13	a little	0.24	0.42
CaO	0.02	0.15	0.21	1.10	0.87
Na_2O	4.98	1.36	3.46	3.43	4.14
K_2O	4.01	6.01	3.52	4.90	4.49
H_2O–110°C.	....	0.08	0.18	0.68	0.22
H_2O+110°C.	0.64	0.60	0.61	0.73	0.54
TiO_2	....	0.15	0.11	0.08	0.44
P_2O_5	....	trace	trace	0.03	0.13
ZrO_2	....	0.05	....	....	....
MnO	....	trace	....	0.06	0.06
SrO	....	trace	....	trace	....
BaO	....	0.06	0.05	trace	....
Li_2O	....	trace	....	trace	....
NiO	....	....	....	....	0.20
CO_2	....	....	....	0.77	....
Total	100.01	100.37	100.02	100.18	99.87

I. Quartz porphyry (leopardite), one and a half miles east of Charlotte, Mecklenburg county, North Carolina. *American Journal of Science*, Vol. XXXIII (1862, 2d ser.), p. 198. F. A. Genth, analyst.

II. Quartz porphyry—two and a half miles northwest of Blowing Rock, Watauga county, North Carolina. Petrographic data by Arthur Keith. Contains quartz and orthoclase, with subordinate sericite, chlorite, and biotite. W. F. Hillebrand, analyst. *Bulletin No. 168*, U. S. Geological Survey, p. 52.

III. Spherulitic rhyolite—Sam Christian gold mine, Montgomery county, North Carolina. Described by J. S. Diller, *American Journal of Science*, Vol. VII (1899, 4th ser.), p. 341. W. F. Hillebrand, analyst. *Bulletin No. 168*, U. S. Geological Survey, p. 53.

IV. Quartz porphyry.—Yogo Rock, sheet at head of Belt and Running Wolf Creeks, Little Belt Mountains, Montana. Described by Weed and Pirrson. *Twentieth Annual Report*, Part III, U. S. Geological Survey, pp. 520 ff. W. F. Hillebrand, analyst. *Bulletin No. 168*, U. S. Geological Survey, p. 125.

V. Quartz porphyry.—Six miles east of Ironton, Missouri. Described by E. Haworth, *Annual Report*, Missouri Geological Survey, Vol. VIII, 1894, p. 181. Melville, analyst.

WEATHERING.

In some exposures of the leopardite the weathered surface of the rock, which is still hard and firm, presents a lusterless, dead, chalk-like whiteness, the black spots of which are more or less bleached, changed from black to a reddish-brown in color. This alteration is brought out fairly well in Fig. 4, which is a photograph of a hand specimen of the partially weathered rock, reproduced one-half natural size. Bleaching of the spots is more emphasized along the top of the specimen, shown in the figure (4) in the contrasted lighter color of these spots to others in the same figure. When Fig. 4 is compared with those of the fresh rock, Figs. 1, 2, and 3, it is noticeable that all the spots in it have undergone some leaching, as indicated in their color being less intense or deep than for those in the fresh specimens of the rock.

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QUARTZ-FELDSPAR-PORPHYRY (GRANIPHYRO LIPAROSE-ALASKOSE) FROM LLANO, TEXAS.

THERE occurs in the vicinity of Llano, Tex., a porphyry which is very interesting petrographically, and may prove equally so commercially. It forms a large body whose shape and geological occurrence have not yet been described. It is said to be quite uniform in character. The material submitted by Dr. William B. Phillips, Director of the University of Texas Mineral Survey, for petrographical study is a gray porphyry with abundant phenocrysts of red feldspar and blue quartz, the matrix or groundmass being aphanitic to phanerocrystalline. It appears to have a crystalline texture, but the individual grains are not distinctly visible without a microscope. The rock is therefore mottled red and gray, with light blue spots of opalescent quartz.

The phenocrysts vary in size, the largest feldspars being 10^{mm} in diameter, the largest quartzes 5^{mm}. The quartzes exhibit a beautiful blue color, which is light sky-blue in the central part of the crystal and dark at the margin. The crystals are not all colored to the same degree; some are lighter than others. The color does not change perceptibly with a change in the angle of incidence, or in the position of observation, except that in certain positions there is a brilliant light blue luster. The feldspars are rather uniformly colored light Indian-red, the larger crystals being mottled with gray.

The proportion of phenocrysts and groundmass estimated from the surface of the specimen and from three thin sections is:

Phenocrysts	quartz	10.7
	feldspar	26.5
Groundmass		62.8
		100.00

Under the microscope the groundmass is seen to be holocrystalline and microcrystalline, and is composed of feldspar and quartz in nearly equal proportions, together with a small amount of brownish-green mica, and still less fluorite, magnetite, apatite, and zircon.

The proportions in which these occur was determined by microscopical measurement to be approximately, in 62.8 per cent. of groundmass:

		Total
Quartz,	23.9	34.6
Feldspar,	29.2	55.7
Biotite,	8.6	8.6
Fluorite,	1.0	1.0
Apatite,	0.13	0.13
	62.83	100.03

The fabric of the groundmass is uniformly heterogeneous, being a mixture of automorphic granular and micrographic. It consists of anhedrons of quartz, very free from inclusions, except some minute gas cavities, with similarly shaped anhedrons of microcline slightly clouded with alteration products, besides anhedrons of twinned albite with an approach to automorphism. These anhedrons vary in size from 0.1 to 0.01^{mm} in diameter. Throughout the whole are scattered at short intervals granular clusters of graphic intergrowth of quartz and feldspar. The crystallization of the graphic parts was almost contemporaneous with that of the anhedrons, as these are developed in continuous orientation with the graphic clusters.

The mica is xenomorphic in great part, and is in about the same sized anhedrons as the quartz and feldspar. It appears to have been almost contemporaneous in crystallization with these minerals. Its color is green to brownish-green.

Fluorite occurs in irregularly shaped anhedrons, xenomorphic in form. It is colorless in thin sections, exhibits distinct cleavage, and is characterized by its low refraction and isotropic behavior. It is quite uniformly scattered through the groundmass.

Apatite occurs in colorless microscopic prisms. Magnetite and zircon both occur in anhedrons in such small quantities that they were not measured. They appear to constitute a small fraction of 1 per cent. of the rock.

A careful study of the feldspars in the groundmass showed that microcline and albite are present in nearly equal proportions, and that they form separate and distinct crystals not perthitically intergrown.

The feldspar phenocrysts are microcline, with extremely minute and regular multiple twinning in two directions. The delicacy of the twinning suggests a possible soda content in the potash feldspar approaching soda microcline. There is also a perthitic inclusion of albite in irregularly shaped shreds, and also a slight clouding due to alteration, which is probably kaolin with hydrous oxide of iron which gives color to the feldspar.

The quartz phenocrysts contain multitudes of minute inclusions, rather evenly distributed through each crystal, except for a margin of nearly pure quartz in some cases. The inclusions are of two kinds, generally intermingled: one consists of extremely thin, colorless prisms, sometimes passing into lines of minute grains, like broken prisms; the other kind is in equally thin tabular crystals with six sides and trigonal shapes, and a light brown color. The colorless prisms have higher refraction than quartz, but the double refraction is not recognizable. They resemble apatite rather than rutile, having lower refraction than rutile and not being so long as rutile needles often are. The width of these prisms varies from 0.000800^{mm} to much less; that is, it is mostly a fraction of a wave-length of light. The brownish tabular crystals are equally thin, and range in diameter from 0.004^{mm} to much less. Studied by incident sunlight, they exhibit metallic reflections of a bluish-white and also of other colors. They have the crystal form and color of ilmenite.

These inclusions lie at all angles within the quartz crystals, but there appear to be sets of parallel directions intersecting at various angles, so that in some positions many tabular microlites reflect light in one direction. The same is true of the colorless needles. They lie in parallel lines crossing at various angles, whose orientation with respect to the inclosing quartz does not appear to be definite.

The sky-blue opalescent color of the quartz phenocrysts is undoubtedly due to reflection of blue light-waves from the minute colorless prisms, whose width is a fraction of the length of light-waves. It is similar to the blue color of the sky. It is probable, however, that there is also blue light produced by interference of the light reflected from both sides of the minute tabular crystals, whose thickness is also of the order of a fraction of a light wave-length; so that both kinds of phenomena occur within these quartzes.

From the microscopical measurements of the minerals and the optical characters of the feldspars it is possible to estimate approximately the chemical composition of the rock. The feldspars appear to be albite and orthoclase (potash microcline) in almost equal proportions in the groundmass, and the phenocrysts appear to have these molecules in nearly the same proportions. In assuming a chemical compositon for the brownish-green mica, the analysis of that in the soda granite (grano-liparose) of Cape Ann, Mass.,[1] was chosen.

On this basis the chemical composition of the rock was calculated to be that given in column I. This was done before chemical analyses of the rock were made, and the result is of great interest as showing how far this method of estimation may be relied on in favorable cases. If the microscopical measurements had been made to include the magnetite and zircon, the result would have been still more elaborate. Subsequently Analysis II was made by Mr. S. H. Worrell, of the University of Texas Mineral Survey, on a sample of the rock from the land of Mr. H. C. Harned, near Llano, Tex. As the alkalies were not separately determined in this analysis, Dr. H. S. Washington very generously undertook to analyze material from the specimen studied microscopically. The result is given in Analysis III. From

	I	II	III	IV
SiO_2	74.52	74.9	75.90	74.80
Al_2O_3	11.58	11.1	12.07	11.44
Fe_2O_3	0.69	1.6	1.01	1.07
FeO	2.61	1.5	1.45	1.62
MgO	none	......	0.22	0.28
CaO	0.82	0.2	0.65	0.80
Na_2O	3.40	8.5	3.08	3.32
K_2O	5.46	tr.	5.32	5.52
H_2O+ / H_2O-	0.36	0.3	0.41 / 0.06	0.23
TiO_2	0.29	0.5	0.38	0.40
P_2O_5	0.05	......	0.15	0.05
F	0.49	......	n. d.	0.49
CO_2	......	......	none	......
MnO	0.02	1.9	n. d.	0.18
	100.29 less 0.21	100.4	100.70	100.20 less 0.21
	100.08			99.99

[1] See Table XIV in *Quantitative Classification of Igneous Rocks* (Chicago, 1903), mica analysis *e*.

these analyses it will be seen how close the microscopically estimated chemical composition is to that determined by chemical analysis.

The higher silica in III shows that the quartz in the rock was underestimated by 1.5 per cent., or that the piece analyzed by Dr. Washington was slightly richer in quartz phenocrysts.

The following data were determined in the laboratory of the Mineral Survey of the University of Texas: Specific gravity, 2.64; corrected, 2.67. One cubic foot of the rock absorbs 9.47 ounces of water. Crushing strength, 15,300 pounds per square inch of surface.

The alkalies in I and III are remarkably concordant, proving that the determination of the feldspars by optical means was correct; The lime determined in III corresponds to that estimated optically in fluorite and apatite. Fluorine appears only in Analysis I, and is very nearly correct, probably as much so as if determined by chemical means.

The correspondence between the two oxides of iron in both chemical analyses, II and III, the discrepancy in Anlaysis I, and the presence of a small amount of magnesia in III show that the mica analysis chosen from the Cape Ann rock is not the proper composition for the mica in the porphyry under investigation. The probable composition of this mica may be found by subtracting from Analysis III the chemical constituents of the known minerals—quartz, feldspar, fluorite, and apatite—and reckoning the remainder as mica and the extra quartz already mentioned. The result is as follows: extra quartz, 1.37 per cent.; mica, 8.6 per cent., having the composition (*a*).

	(*a*)	(*b*)		(*a*)	(*b*)
SiO_2	32.1	35.26	K_2O	6.8	9.20
Al_2O_3	19.2	10.24	H_2O	5.5	2.71
Fe_2O_3	11.7	12.47	TiO_2	4.4	4.68
FeO	16.8	18.84	MnO	.....	2.14
MgO	2.5	3.24			
CaO	0.8	0.05		99.8	99.34
Na_2O	.....	0.60			

This is approximately the composition of a lepidomelane like that in the nephelite-syenite (*grano-nordmarkose*) of Litchfield, Me.,[1]

[1] *Loc. cit.*, mica analysis *f*.

with a slight difference in the oxides of iron, and a notable amount of titanium oxide. It closely resembles the analysis (*b*) of lepidomelane from nephelite-syenite from the neighborhood of Langesundfjord, Norway, by Scheerer.[1] If this analysis of mica is used in the calculation of the chemical composition of the rock, the result is that given under IV.

The mica is clearly a lepidomelane rich in iron and alumina and poor in magnesia. When a greater variety of micas has been separated from igneous rocks and carefully described and analyzed, it will be possible to estimate the chemical composition of a rock from a microscopical investigation with greater accuracy.

The rock from near Llano, Tex., may be called a quartz-feldspar-porphyry having the composition of a granite. In the "Quantitative System of Classification" it is a graniphyro-liparose-alaskose.

The norm calculated from Dr. Washington's analysis, III, with the addition of fluorine determined microscopically from fluorite is given below under (1). The norm calculated from the mode by means of estimated Analysis IV is given under (2):

	(1) Norm	(2) Norm from Mode	Mode
Quartz	36.90	33.30	34.6
Orthoclase	31.14	32.80	27.8
Albite	26.20	27.77	27.9
Corundum	1.33	....	....
Hypersthene	1.69	2.42	Biotite 8.6
Magnetite	1.39	1.62	tr.
Ilmenite	0.76	0.76	tr.
Apatite	0.34	tr.	0.13
Fluorite	0.70	1.00	1.00
	100.45	99.67	100.03

The rock is a persalane with about 5 per cent. of femic components. Following the norm from Dr. Washington's analysis, the quartz is so abundant that it is quarfelic, columbare, near the quardofelic order britannare. It is therefore a britannare-columbare. It is peralkalic of the most extreme kind, having no anorthite feldspar, the lime being entirely femic, in fluorite and apatite. It is alaskase near liparase, a liparase-alaskase. And with respect to

[1] See W. C. Brögger, *Zeitschr. Kryst. Min.*, Vol. XVI (1890), p. 191.

alkalies it is sodipotassic, and hence an alaskose near liparose: *liparose-alaskose.* If the norm derived from the mode were made a basis of classification, the rock would be quardofelic, a britannare, near columbare. From this it is evident that the rock is intermediate between these orders, and may be a liparose-alaskose, or an alaskose-liparose.

JOSEPH P. IDDINGS.

CRYSTOSPHENES OR BURIED SHEETS OF ICE IN THE TUNDRA OF NORTHERN AMERICA.

SHEETS or layers of clear ice have often been recorded as occurring in the alluvial deposits or in the sphagnum swamps of Arctic or sub-Arctic America, and most of the travelers who have made even short visits to the far north have noticed the occurrence of these ice-sheets in small escarpments on the edge of the tundra. I myself observed them in a number of places along the southern edge of the Barren Lands, in the country between the Mackenzie River and Hudson Bay, and drew attention to the fact that some of them, at least, were moving slowly down the gentle slopes on which they were lying. Since coming to the Yukon Territory I have had many opportunities of seeing and examining them in the frozen bogs which cover the bottoms of most of our valleys.

As the mode of formation and growth of these ice-sheets for a long time appeared to be rather difficult to explain, the following remarks with regard to them may be of interest.

The Klondyke gold-bearing district, to which my observations have lately been confined, and in which the deductions here set down were drawn, is a part of a great unglaciated belt or tract of country lying near the middle of the Yukon Territory in Canada, between the glaciated region which extends on both sides of the "Chilcat" or Coast Range of mountains to the south and southwest, and the also glaciated region of the Ogilvie or Rocky Mountain range to the north and northeast. It is a country of high, well-rounded hills and deep, though flaring, valleys, in the bottoms of which flow streams with regularly decreasing grades. On one or both sides of these streams are everywhere deposits of alluvial material, varying from ten to a hundred feet in depth, consisting below of coarse sand and gravel, above which are fine sands with peaty and vegetable material, the uppermost layer, locally known as "muck," usually consisting almost exclusively of sphagnum swamp. The streams flow on beds of the coarser alluvial gravel or sand, seldom touching the underlying rocky floor, and are at present confined in relatively

shallow channels, the sides of which consist of the peaty and finer alluvial material. Ponds or lakes are conspicuously absent.

The surface of the whole country, whether composed of "muck," gravel, or rock in place, is almost everywhere permanently frozen, and while as yet comparatively few shafts have been sunk through this frozen layer, the evidence at hand would seem to show that it

FIG. 1.—Ice formed by spring water in winter.

has a thickness varying from forty or fifty feet on the higher, uncovered parts of the hills, to two hundred feet in the moss-covered bottoms of the valleys. Here and there, however, there are unfrozen channels in the otherwise frozen layer, through which springs issue from the sides of the hills, carrying water from the deeper saturated, and unfrozen ground through the frozen layer to the surface.

Most of the known springs issue from the rock above the surface of the alluvial deposits in the bottoms of the valleys, but some have been exposed by mine workings beneath the ordinary surface levels. They all discharge more or less water throughout the year,

their flow being but slightly, if at all, affected by the conditions of the weather, or even by the most extreme seasonal changes of temperature. In summer those that issue from the rock above the alluvial deposits discharge over the surface into the nearest brooks or rivers, and, except where used as local supplies of clear cold water for household purposes, are rarely noticed; but in winter, when the thermometer occasionally falls as low as —60° F., the water flowing out into the cold air freezes within a comparatively short distance, and by the close of the winter it may have formed a mass of ice many feet in thickness. These ice-masses are locally known as "glaciers," and where they form along the lines of roads are often serious obstructions to travel.

But, in addition to these masses of ice formed on the surface every winter, and which regularly melt away during the following summer, other masses are formed beneath the surface in such positions that they are protected from the action of the sun and atmospheric agencies; and thus it is possible for them to increase from year to year to very considerable dimensions. These underground masses of clear ice are also locally known in the Klondyke country as "glaciers," but the name "crystosphene" (κρύσταλλος "ice"; σφήν, wedge") is here suggested for them, as indicating a mass or sheet of ice developed by a wedging growth between beds of other material, while the name "crystocrene" (κρήνις, fountain), is suggested for the surface masses of ice formed each winter by the overflow of springs.

Crystosphenes are formed by springs which issue from the rock under the alluvial deposits that cover the bottoms of the valleys. As a rule, they occur as more or less horizontal sheets of clear ice, from six inches to three feet or more in thickness, lying between layers of "muck" or fine alluvium, usually where the "muck" is divided horizontally by a thin bed of silt or sand; and most of them, as far as my observation goes, are from two to four feet below the surface, though some are deeper. In area they differ greatly. One observed by the writer on the shore of Daly Lake, near the southern edge of the Barren Lands west of Hudson Bay, seemed as if it might underlie a square mile or more, while many of those in the bottom lands of the gold-bearing creeks of the Klondyke district vary in length from a hundred to a thousand feet, and in width from fifty

to one or two hundred feet, as shown by shafts sunk through them at various places.

Speaking generally, these ice-sheets are of very even and regular thickness throughout, though they are not strictly horizontal, but approximate closely to the slope of the surface under which they lie. For instance, the city of Dawson is built on an alluvial bottom land declining gently from the base of a steep hill to the banks of the Yukon and Klondyke Rivers, and a crystosphene which here underlies the surface at a few feet beneath it seems to have about the same slope. In another case a crystosphene was encountered on a mining claim on Hunker Creek three feet below the surface, and it was traced for five or six hundred feet down the valley, being everywhere at practically the same depth, while the surface itself had a slope of about one in a hundred, so that this apparently level sheet of clear ice was five or six feet higher at its upper end than at its lower. Examples of this kind could be multiplied almost indefinitely, showing plainly that these ice-sheets do not partake of the character and attitude of frozen ponds or lakes.

While these crystosphenes, or so-called "glaciers," are usually of the nature of nearly horizontal sheets, occasionally they occur as veins or dikes of ice rising through the bed-rock into the overlying gravel. Two such veins of ice were very well exposed in the underground workings on mining claim No. 39, below Discovery on Hunter Creek, where they evidently represented the former course of a spring, which had changed its point of discharge. More or less vertical masses of ice are also sometimes met with in the gravels themselves, indicating the positions of former water channels from the bed-rock toward the surface.

In the majority of cases crystosphenes are in the vicinity of springs that can be plainly seen issuing from the bases of the neighboring hills, but in other cases no such springs are apparent. In these latter cases, however, wherever the gravel has been removed, and the underlying rock has been exposed, springs have been found. While studying the origin of the crystosphene 600 feet long, already mentioned as occurring on Hunker Creek, no springs were apparent in the immediate vicinity, and at first it seemed as if the ice must have been formed from water flowing from a spring three or four hundred yards farther up the valley; but finally a little trickling

stream was found issuing from the rock several feet below the level of the top of the alluvial deposits. This was the source of the water that had formed the ice.

The mode of formation of these underground sheets of ice is therefore somewhat as follows:

Water, issuing from the rock beneath a layer of alluvial material, rises through the alluvium, and in summer spreads out on the surface, tending to keep it constantly wet over a considerable area. In winter, if the flow of water is large, and the surface consists of incoherent gravel, the water will still rise to the surface, and there form a mound of ice. If, on the contrary, the flow from the spring is not large, and the ground is covered with a coherent mass of vegetable material, such as is formed by a sphagnum bog, the spring water, already at a temperature of 32° F., rises till it comes within the influence of the low temperature of the atmosphere above, and freezes. This process goes on, the ice continuing to form downward as the cold of the winter increases, until, a few feet below the surface, but still within the influence of the low external temperature, a plane of weakness is reached in the stratified and frozen vegetable or alluvial deposit, such planes of weakness being generally determined by the presence of thin bands of silt or fine sand.

As any outlet to the top is now permanently blocked, the water is forced along this plane of weakness, and there freezes; and thus the horizontal extension of the sheet of ice is begun. While thus increasing in extent, the ice also increases in thickness by additions from beneath, until it has attained a sufficient thickness so that its bottom plane is beyond the reach of the low atmospheric temperature above; after which it continues to increase in extent, but not in thickness or depth.

With the advent of the warm weather of summer the growth of the crystosphene ceases, but the cold spring water which continues to rise up beneath it has very little power to melt it, and its covering of moss or muck, being an excellent non-conductor of heat, protects it from the sun and wind, and prevents it from thawing and disappearing. Thus at the advent of another winter it is ready for still greater growth.

J. B. Tyrrell.

Dawson, Yukon Territory, Canada,
February 13, 1904.

A COAL-MEASURE FOREST NEAR SOCORRO, NEW MEXICO.

We have grown so accustomed to consider that in the Rocky Mountain region the period represented in the eastern states by the deposition of coal was inimical to terrestrial life, or otherwise so different from the corresponding eastern time in its conditions that it is useless to search for a coal flora, that considerable interest attaches to any area, however restricted, in which a genuine Coal-Measure flora is present.

Such an area became known to the writer a number of years ago, but it long proved impossible to study the locality in person. A small suite of fossils reported to have been collected in the fire-clay beds east of Socorro was placed in the writer's hands by Mr. George Thwaites, and, after several fruitless attempts to identify the locality, the occurrence was reported, and, later, figures were given of four species of lepidodendrids which could be distinguished as distinct. There figures occur on Plate VII of the *Bulletin of the University of New Mexico* for 1900. No descriptions were given, and considerable uncertainty still existed as to the age of the formation from which they were derived.

More recently the writer has not only been able to locate the place and add to the original collection of specimens, but he has carried out a considerable amount of field work in the immediate locality which will suffice to settle the principal questions of stratigraphy so long left open.

Whenever the nature of the contact between the granite and the superjacent rocks shall be studied carefully throughout the territory, many interesting points will be brought out. Whether the granite itself is a homogeneous element or represents various periods must be left an open question. We have every reason to conclude that it represents the metamorphosed sediments of an early geological time, and the writer has already reported instances where limestone beds within the granite have been found to contain what greatly resemble altered organic remains. It is also known that the gran-

ites, in common with the immediately overlying strata, have suffered great erosion in the early part of the so-called Permian. This period of elevation, disturbance, and oscillation does not, however, seem to mark any great lost interval, so far as the record shows, while the interval represented by the granite contact is undoubtedly a considerable and variable one. The disturbance which lifted the granites above the reach of the sea may not have been very extreme, and it is not likely that the present extreme of metamorphism was reached till long after, though it was certainly before the time in which the breccias and sandy beds of the Permian were formed, for these strata contain granite fragments in abundance.

At any rate, when the sea began to return by subsidence of the granite, this encroachment was gradual, and from the south toward the north and northwest. This is proved by the fact that the exposures in the southeastern counties reveal vast deposits between the granite and the Carboniferous in which we have identified strata as old as the Burlington, superposed upon others yet older, but not identified as yet. In the southwestern part of New Mexico there are still earlier strata, some of which have been referred to the Devonian (*Hamilton*). The writer hopes to enter upon this subject more in detail in another place; at present it will be sufficient to indicate that as far north as in Socorro county the stratified rocks overlying the granite have revealed no remains indicating an age earlier than the Carboniferous, and the writer knows of no positive datum representing anything older than the Coal Measures. It is true that there are reports of Subcarboniferous crinoids from the Graphic-Kelly beds lying upon the crystallines near Magdalena, but inasmuch as this 100 feet or more of crystalline limestone, which is so interestingly developed in the lead district, is not found in the locality under discussion east of the Rio Grande, nor yet farther north in the Rio Grande valley, it may be said roughly that the boundary between the lower formations and the Coal Measures passes through Socorro county.

Corresponding to the change just described is a still more pronounced geographical change in the character of the Permian and "red bed" deposits, which have an entirely different facies and succession in the northwestern counties from the typical Texas sequence exhibited in the southeast.

The writer has described the Rio Grande valley as a region of early uplift—in effect an anticline, though the anticlinal axis is not exposed to view—and accordingly the dip of the strata is prevailingly to the west on the west side and to the east on the eastern side of the valley. The granite core of this anticline is largely removed, but is exposed in the bases of the Sandia, Manzana, San Andres, and Organ mountain ranges on the east side of the valley, as well as in the core of the great Sierra Ladrone uplift and the base of the Limitar Mountain on the west.

The interval between these remaining buttresses of the great eroded mass is now, for the most part, filled with late strata composed of Tertiary (Santa Fé marls) and Pleistocene deposits, mostly nearly horizontal, except in proximity to the areas of late volcanic disturbance. There are also perforating necks and cones of basalt, as well as interstrata flows and dikes of the same material, but of an older period.

In the *American Geologist* of recent date[1] the writer announced the discovery of granite masses in the valley in the midst of the Tertiary beds, and gave a section extending from the Rio Grande east of Socorro through these granitic bosses. This section is so taken as to pass through the region here under discussion, though it does not cut the exact locality in which the fossil coal flora was found.

These granite ribs (Fig. 1) are two in number, and are separated by an interval of perhaps half a mile, which is partly covered by the Tertiary beds, but, wherever cut by arroyos or canyons, the lower or Sandia formation of the Coal Measures is exposed in basin-like relation upon the granite, forming a shallow syncline (really a modified monocline). The western rib or elongated boss of granite rises not over 100 feet above the canyon level, and presents a sharp slickensided fault to the west, with a course some twelve degrees east of north where measured. In some places the Tertiary wholly covers the boss, and to the north and south the granite passes out of sight beneath this formation, the entire length being perhaps two miles, as exposed. The eastern exposure presents the overlying but unconformable Coal-Measure formation consisting of shales, silicious shale, quartzite, and ferruginous conglomerate near the contact,

[1] "Laws of Formation of New Mexico Mountain Ranges," May, 1904.

followed by a large series (over 200 feet) of alternating shales, quartzites, and earthy or sandy limestones, the latter being quite fossiliferous.

Of the Graphic-Kelly formation which in the Magdalena Mountains, a few miles to the west, separates the Sandia series from the granite, there is no trace.

The Coal-Measure rocks soon become horizontal, and at the eastern side of the basin, where they abut upon the eastern boss or rib of granite, they dip to the west and lie in juxtaposition to a fault exactly similar to that on the western side of the first-mentioned or western rib. In fact, the eastern rib is to all intents a repetition of the first,

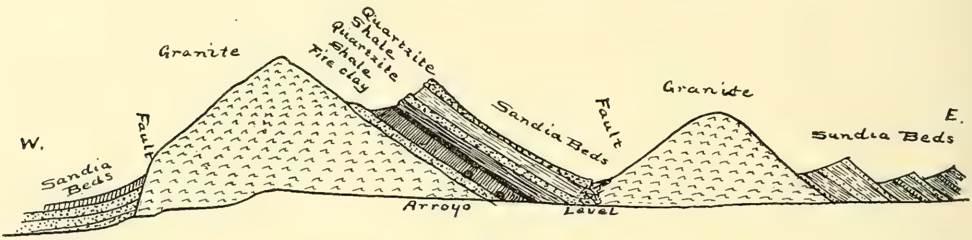

FIG. 1.

and the Sandia series is repeated on the eastern aspect in all essential respects as it occurs to the east of the western granite rib.

Locally, however, there is a third fault which serves to repeat the granite. This fault is a few hundred yards east of fault No. 2, and in the interval there are preserved a few of the Sandia strata, though in many places they are entirely removed by erosion. It is in the V formed by these two faults that the best example occurs of the fire-clay beds with the inclosed plant remains. In other localities the fire clay also occurs beyond the influence of this local fault, but these points are as yet little explored, and, in several localities visited, the granite contact has only a silicious shale in the place of the fire clay.

The dip of the strata as they repose on the granite may be as high as 70 degrees, but more often about 45 degrees. Passing eastward, one crosses in succession a number of low hills, each capped by a bed of quartzite, the intervals being filled with shale and limestone, the superior resistance of the quartzites having thus impressed itself upon

the topography. When the top of the Sandia formation is reached, the topography changes, and the country rises in abrupt escarpments of massive to earthy limestone of the characteristic Upper Coal-Measure habitus. At the base, this formation is locally very fossiliferous with the well-known Coal-Measure assemblage, a partial list of which will be given below.

The first escarpment may rise some 100 to 150 feet, and is followed by others of the same character, indicating a probable aggregate thickness of 300 to 500 feet. The continuity of the section is here broken by what may be called the "Cane Spring monocline" or fault zone. This will be more particularly described later on, and it will here be noted that this break forms in effect a rough delimitation of the Carboniferous from the so-called Permian. To the east of this the hills are mostly composed of earthy limestones, with shales of prevailingly reddish color, with gypsum beds and calcium anhydrite deposits to the base of the great escarpment forming the sky-line to the spectator from the west side of the river at Socorro. This ridge, which is the southern continuation of the Cibolo (Seboyo) Mountains, consists of from 500 to 600 feet of red beds, with gypsum and anhydrite inclusions, capped by 150 to 175 feet of yellowish sandstone and 100 to 200 feet of gray, massive, non-fossiliferous limestone, with at least one small band of quartzite. Still to the eastward are hills containing the typical upper red-bed formations. To the south this whole series disappears beneath the Carthage coal fields of Cretaceous age.

To return to the plant beds, it will be noted that the fire clay, with its attendant shales, reposes directly upon the granite, or with a thin layer of quartzite between. The clay is of good quality, but very irregular, and has formed the base of the fire brick manufactured by the Socorro Fire Clay Co. In the clay, and especially in the shales overlying, are the remains of lepidodendrids and other coal plants referred to. A thin seam of coal is apparently present, though at the time of our inspection there was no opportunity to discover it in place. Report affirms that a boring one and one-half miles south encountered two small coal seams within 200 feet.

The thickness of the clay and attendant shales is not over 30 feet, of which half may be roughly estimated as clay. Then follows 10

feet of silicious shale capped with quartzite, and 15 feet of similar shales also capped with about 5 feet of quartzite. This is all that remains of the great Sandia beds at this place, but to the east, on the other side of the third granite mass, the series is complete. This occurrence may be termed the "Incarnacion" fire clay, and the same name will apply to the granite exposure, it being the name of the mining district in which these exposures occur.

There would seem to be no reason for separating the fire clay from the Sandia formation, it being but a local variation, and, even where the clay is not found, obscure plant remains attest the similarity of conditions to some extent.[1]

The Cane Spring fault area.—In this connection it may be desirable to call attention to this profound dislocation, the exact nature of which varies from point to point, but which is apparently found at a distance of a mile or more to the west of the main escarpment of the Cibola ridge. It lies nearly midway between the Incarnacion granite ribs, with their faults, and the main range just mentioned. The typical exposure is, however, at "Ojo de las cañas," or Cane Spring, a permanent water in the large arroyo joining the Rio Grande immediately south of Socorro and owing its existence to the faulted area. A section extending from the fault to the Cibola ridge is given, the data being approximate, but sufficient to give some idea of the conditions.

The disturbance is profound and has the appearance of being a double anticline with an interval separating the two members of some eighth of a mile. At Cane Spring, where the disturbance is most easily seen, about 700 feet of red, green, and yellow sandstone, shale, and marl are tilted up at a high angle, with the appearance of an appressed fold, the dip being to the west on the west side and to the east on the opposite side of the axis. The western limb is concealed by a covering of Tertiary, but on the east is a sharp fault, against which the nearly horizontal strata abut with little inclination. Thence eastward there are exposed by the arroyo about 100 feet of red and yellow sand and marl to the second break, which is very similar to the

[1] Since writing the above, similar plant remains (*Lepidodendron* sp., same as Fig. 9 below) have been found in the lower part of the Sandia series on the west side of the Ladrones Mountains, where the Sandia quartzite reposes directly upon the metamorphic rocks (schists and granites).

one just described. The section figured (Fig. 2) is a mile or more north of the spring, but has a similar double character. It is impossible to be certain that the disturbance is due to a double appressed fold separated by faults, but such is the appearance. At this locality the western side of the break is also exposed, and is a distinct fault, with much alteration and excretion of quartz. A curious quartz breccia is a feature of the fault on the western side. The upper Coal Measures or Permo-Carboniferous appears on the west, and about half a mile west of the fault we found fossils including *Phillipsia major* and other types known to be well up in the series.

Unfortunately, the paleontology of the Sandia series is too little known at present to enable us to locate it definitely with respect to the divisions now recognized in the Middle West. We have determined in it, immediately above the fire clay beds, *Productus costatus*, *Spirifer cameratus*, *Ambocoelia planoconvexa*, *Seminula argentea* (small form), *Derbia crassa* (?), bryozoa, etc. In the lower part of the division immediately following the Sandia beds there is a large fauna, of which the following may be mentioned: *Eupachycrinus verrucosus*, *Reticularia lineatus*, *Ambocoelia planoconvexus*, *Spirifer striatus*, *Spirifer cameratus*, *Productus cora*, *Productus nebracensis*, *P. semireticulatus*, *Seminula argentea* (large form), *Derbia crassa*, *Chonetes granulifera*, *Dielasma bovidens* (rare at this horizon, abundant higher up), *Streblopteria* (?). It may be noted that *Eupachycrinus* is known in the Kansas section from the Earlton to the Severly, *Chonetes granulifera* commences in the

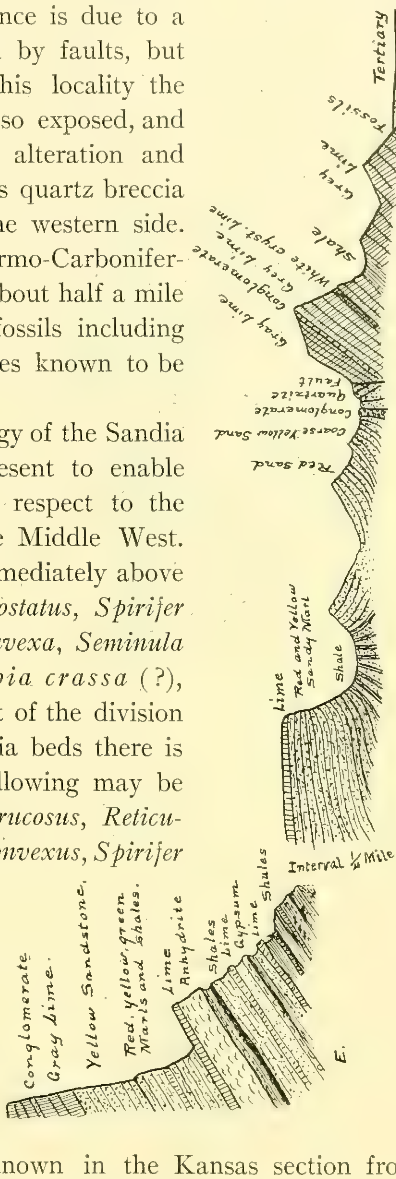

Fig. 2.

Leucompton beds and extends upward, *Streblopteria* begins in the Earlton. So far as can be determined at this writing, the position is near the horizon indicated by Iola limestone, or within the Pottawatomie formation of Haworth. This is above the base of the Upper Coal Measures.

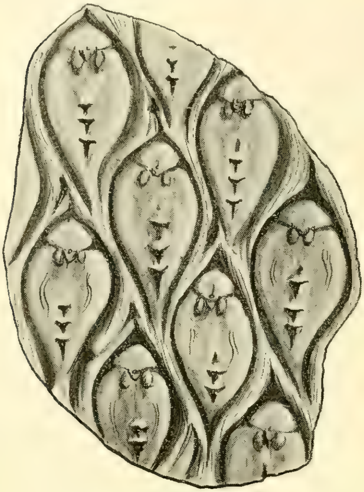

FIG. 3.—*Lepidodendron thwaitesi*, sp. n. (One-half natural size.)

Below are given in tabulated form, for comparison, some of the more complete sections across the Permo-Carboniferous. It will be found that there is always a well-marked change in lithological character of the rock at the horizon of the Manzano quartzite. Here is evidence of an unconformity by overlap. The lime breccias or small strata of lime with angular fragments of earlier lime and granite are quite characteristic of this general belt, and the Manzano beds themselves usually contain vast quantities of red granitic débris. Often vein quartz is present, and it is also common to find impressions of tree trunks. All of these phenomena indicate proximity of land and a period of disturbance. The Sandia formation is easily distinguished, but it is more difficult to decide upon divisions of the Upper Coal Measures above that section. In general, there is a change of fauna, though numerous species pass unchanged throughout. *Productus punctatus*, *Dielasma bovidens*, and *Meekelia* are characteristic of the upper portions. The large *Fusulina* is found at a higher level than the common *F. cylindrica*.

FIG. 4.—*Lepidodendron thwaitesi*, sp. n. (Single bolster, enlarged.)

SECTION EAST OF SOCORRO.

Gray lime - - -	25– 50 ft.
Red quartzite - -	10
Gray lime - - -	65
Whitish to yellow sandstone	150
Red marly beds with lime, etc. - - - -	100–150
Earthy lime - - -	10
Anhydrite - - -	50– 75 ft.
Sandy shales, shales, and lime - - - - -	100
Gypsum - - - -	5
Sandy shales, marls, and lime - - - -	Indef.
Red beds, as above - -	Indef.
Lime (hard greenish, earthy)	10
Yellow sandstone - -	20
Red sandstone - - -	30
Silicious shales	
Alternating shales (quartzites, green limestone, red flags) - - -	300–500
Red granitic conglomerate quartzite.	
Massive limestone (fossiliferous) - - - -	25
Manzano (massive) quartzite - - - -	40– 50
Lime breccia.	

Top of Upper Carboniferous formation (*c* 130).

Massive limestones, shales	60– 75 ft.
Calcareous conglomerate -	5
Limestone - - -	50
Sandy conglomerate (*b*, 147)	5
Limestone - - -	5
Silicious shale - -	2
Earthy limestone - -	35
Massive and shaly lime -	100
Yellow sandstone (*a*, 66 ft.)	15– 20
Shaly lime - - -	6
Massive lime - - -	3
Shaly lime - - -	8
Massive lime - - -	4 ft.
Shaly lime - - -	6
Massive lime - - -	4
Shales and shaly lime -	15

Top Sandia formation (235 ft.).

Red quartzite - - -	4
Red shale - - -	10
Quartzite - - - -	6
Shale - - - -	10
Sandy lime (fossiliferous) -	6
Quartzite - - -	8
Shale - - - -	10
Limestone (fossilferous)	3
Shale - - - -	6
Limestone - - -	4
Shale - - - -	6
Quartzite - - -	4
Shale - - - -	
Limestone - - -	4
Shale - - - -	6
Red coarse sandstone -	20
Green fissile shale - -	25
Earthy limestone - -	5
Sandy shales and quartzite	50
Coarse quartzite - -	8
Clay and shale (Lepidodendrids) - - - -	35
Contact quartzite - -	Indef.
Granite.	

SECTION NEAR COYOTE SPRINGS, SOUTHEAST OF ALBUQUERQUE.

(Permian not exposed; see below.)

Massive limestone - -	10 ft.
Nodular limestone - -	3
Massive limestone - -	4
Shaly limestone - -	28
Granular limestone - -	3
Micaceous shales.	
Coyote yellow sandstone (*b*)	2–30
Massive limestone -	85
Fusulina limestone - -	23
Shale (bryozoa) - -	2

Massive limestone	48 ft.	Sandy lime	17 ft.
Shaly limestone	47	Massive limestone and Sandy shaly lime	28
Massive limestone	15	Fusulina cylindrica beds	
Shales (Flint Ridge beds)	33	Shales	28
Green quartzite	2	*Top of Sandia formation* (119 ft.).	
Massive limestone (productus)	12	Sandy shale, with bands of limestone, alternating with quartzite	45
Nodular shaly lime	2	Silicious fossil lime	2
Massive limestone	30	Sand and shales	22
Black shaly lime	48	Basal quartzite	50
Massive lime	3	Granite or gneiss.	
Lime and lime shales	40		
Sandstone (*a*)	2–4		

Near the locality in which the Coyote section was measured a section was taken which is more complete toward the top and serves to supplement the above section. That part of it above the Coyote sandstone horizon is here given:

Manzano quartzite, red and yellow granitic sand, and conglomerate with silicified wood and granitic pebbles	55 ft.
Top of Upper Carboniferous.	
Earthy lime with lime breccia, etc.	50
Earthy lime with green bands (bryozoa)	25
Earthy cherty lime (*Productus punctatus*)	16
Massive lime (*Productus cora*)	25
Black shaly lime (*Dielasma bovidens*)	17
Bryozoa beds.	
Gray lime (*Fusulina robusta?*)	6
Massive lime	22
Coyote sandstone horizon.	

Below this point the section corresponds essentially with the section given above. This corresponds to a total thickness of the Coal Measures of 750 feet, of which about 130 feet is formed by the Sandia beds. The section east of Socorro contains about 600 feet, of which 235 feet is contributed by the Sandia beds.

In order to indicate the amount of variation in the same region, a section is here given corresponding with that last above recorded and taken only a short distance east of it in the Coyote district:

Massive earthy lime with *Bellerophon*, *Productus punctatus*, etc. *Allorisma* and numerous fossils.	72 ft.
Sandstone	40

Earthy fossiliferous lime	17 ft.
Sandy shale and granular lime	5
Earthy limestone (*Dielasma bovidens*, *Discina*, etc.)	11
Calcareous sandstone	14
Green sandy shale	6
Reddish yellow sandstone (Coyote)	40
Massive earthy lime.	

It appears that this last section falls a little short of reaching the Manzano quartzite and develops a great deal more of the sandy

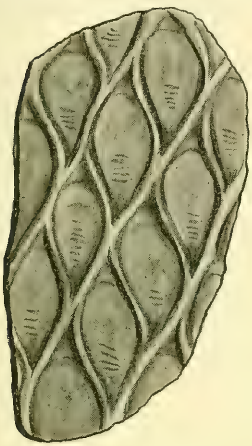

FIG. 5.—*Lepidodendron thwaitesi*, var. *striolatum*, var. n. (One-half natural size.)

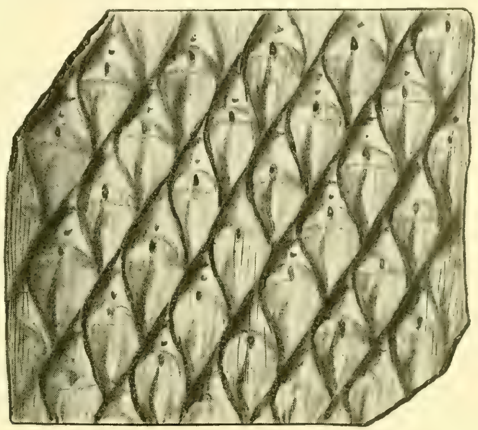

FIG. 6.—*Lepidodendron socorroense*, sp. n. (One-half natural size.)

materials that are found farther west, though the Coyote sandstone has been observed to be 40 feet thick in one place, and entirely absent or reduced to a few inches within the distance of half a mile in continuous exposure.

For comparison, the following incomplete section may be given from the escarpment west of the Rio Grande in about Township 5 N., Range 4 W., of New Mexico P. M. This locality is northwest of the Ladrones Mountains.

Lava flow (basalt).	
Red flags and shales (position uncertain)	200-300 ft.
Fault.	
Limestone with (Permian ?) fossils	15

Limestone and shale	90 ft.
Sandstone shale with lime bands	10
Gray limestone	100
White sandstone	40
Gray (gypsiferous) shales	20
Yellowish sandstone	100
Yellowish shale	5
Reddish gypsiferous shale	175
Anhydrite and limestone resting on fissile shale	100
Gray shales	Unexposed.

Red flags and shales (several hundred feet).

Carboniferous limestone (Coal Measures). At least 400 ft.

The Carboniferous is separated from the detailed section by a valley perhaps a mile wide filled with low hills of the red beds, the dip being in all cases to the east. It is therefore very difficult to determine the thickness of the red beds, nor is it certain that there is no dislocation. There is the same difficulty in determining the extent of the fault at the top of the detailed section, but it is presumed that the throw is small, though there is an area of vertical strata intervening.

FIG. 7.—*Lepidodendron socorroense.* (Enlarged bolster of different form.)

It is not difficult to conclude that the detailed section here given corresponds in a general way with that east of Socorro above the sandy shales, etc., marked as "indefinite." In fact, it would appear that the thick anhydrite bed is a very convenient and rather constant bench mark, however variable it may be in thickness.

References may here be made to the section given in the writer's article on the "White Sands."[1] This section is from a locality comparatively rich in fossils of a decidedly Permian habitus.

PLANTS OF THE INCARNACION CLAYS.

The following descriptions are given as a matter of convenience, in spite of the fact that it has not been possible to compare our specimens with eastern types. The forms seem to be new, and may serve to assist in calling attention to similar occurrences in the Southwest.

[1] *Bulletin of the University of New Mexico*, Vol. II, Fasc. 3, p. 10.

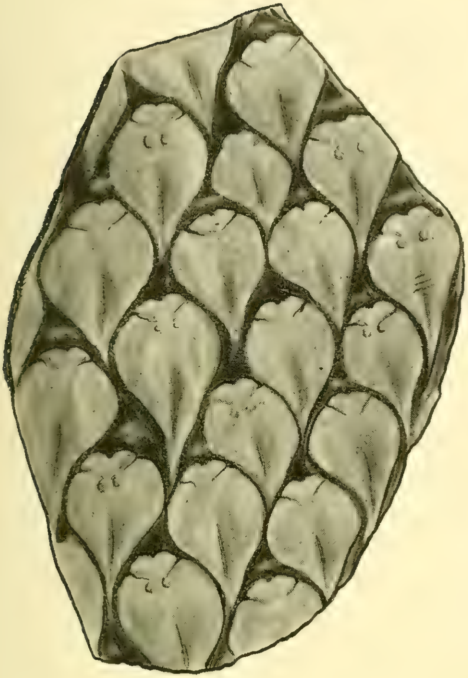

FIG. 8.

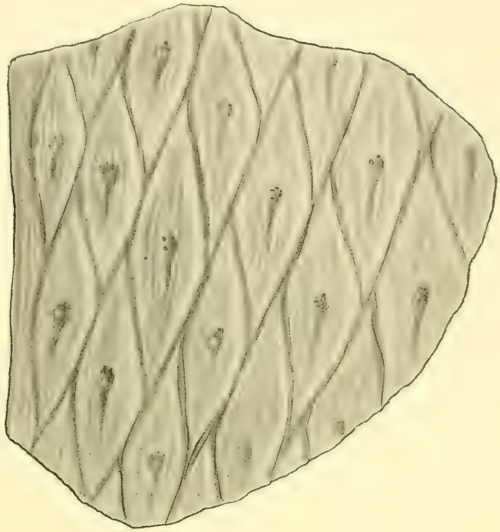

FIG. 9.

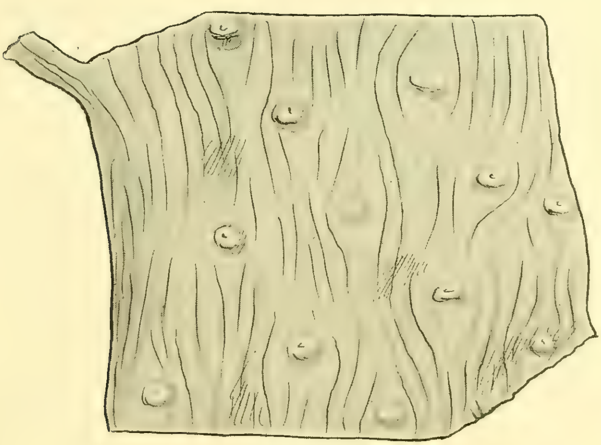

FIG. 10.

FIG. 8.—*Lepidodendron keyesi,* sp. n. (One-half natural size.)

FIG. 9.—*Lepidodendron* sp. ? (One-half natural size.)

FIG. 10.—"*Stigmaria.*" Root of one of the above?

Lepidodendron thwaitesi, sp. n. (Figs. 3 and 4.)

(*Cf. Bulletin of the University of New Mexico*, Vol. II, Plate VII, Figs. 2 and (?) 4.)

Trunks of large size. Bolster somewhat oval, kite-shaped to rhomboidal, about two and one-half times as long as wide, rather thickly set, but separated by high striated ridges; length of bolster, 0.9 in.; width, 0.4 in.; 1.2 in., and 0.45 in., 1.3 in. and 0.5 in., in three cases; seven bolsters in the space of 4.5 in., measured obliquely along the rows in branch over 6 in. in diameter, seven in 5 in. in a larger specimen. Leaf scars (cicatrix) small, transversely oval, about one-fourth as long as entire bolster. Middle of bolster below the cicatrix marked with a ridge or depressed cauda, crossed by three very distinct frets. Transpiring vents well marked on either side below the cicatrix, with which they are connected; vascular trace punctiform, often absent. Ligular scar near apex of cicatrix, triangular, often apparently notching apex of cicatrix. An escutcheon-like impression between transpiratory vents. Leaves sharply acuminate with slender tips, midrib strong, 3 in. wide and perhaps 8 in. long.

Lepidodendron thwaitesi, var. *striolatum*, var. n. (Fig. 5.)

Greatly resembling L. thwaitesi, and perhaps a variety of that species, but represented by smaller specimens in which the preservation is not very perfect.

Bolsters uniformly rhomboidal oval, surface flat, about five in the space of 2.4 in. measured diagonally in the rows. Length, 0.72 in., width, 0.35 in. Space below the cicatrix marked with numerous (5–7) irregular frets. Cicatrix apparently as in *L. thwaitesi*.

Lepidodendron socorroense, sp. n. (Figs. 6 and 7.)

(*Bulletin of the University of New Mexico*, Vol. II, Plate VII, Fig. 1 ?)

Trunks of moderate size, leaves slender. Bolsters rhomboidal to rhombic oval, acuminate at the ends, nearly symmetrical; lower portion, from the leaf scar downward, kite-shaped to rhomboidal, upper margin curved, the long axis marked by a well-defined keel, very prominent near the lower angle, where is an elevation; folar cicatrix about one-fourth the entire length of bolster; transpiratory appendages obscure; vascular pore on the most prominent part of cicatrix; a deep pit below the cicatrix on median line; ligule large, well marked. Bolsters closely approximate, in well-defined oblique series; 0.7 in. long, 0.3 in. wide. In a trunk 3.2 in. in diameter 9 bolsters in space of 3.5 in., measured diagonally in the rows; in larger trunks 9 bolsters in 4.3 in.

This species is well represented, and is variable in size, but the specimens leave much to be desired in detailed structure of the leaf scars.

Lepidodendron keyesi, sp. n. (Fig. 8.)

Trunk of large size. Bolsters large, obovate, flat, closely approximate, in well-defined diagonal rows. Eight bolsters in space of 4 in., measured obliquely

in the rows. Length of bolster, 0.75–0.8 in.; width, 0.5 in. Cicatrix nearly reaching middle of length of bolster; ligule very large, often causing the upper part of cicatrix to appear emarginate. Transpiratory appendages large, oval, discrete. A groove extends from cicatrix to the lower angle of the bolster, and there are traces of frets. State of preservation imperfect. Named in honor of Dr. Charles R. Keyes, of the New Mexico School of Mines.

Lepidodendron, sp. ?. (Fig. 9.)

(*Bulletin of the University of New Mexico*, Vol. II, Plate VII, Fig. 3.)

In form of bolsters this form is like *L. brittsi* or *L. aculeatum.*

All our specimens seem to be decorticated, so that it seems unsafe to attempt a description. It is even possible that these specimens belong to one of the above species, although in appearance they differ widely.

There are five bolsters in a space of 3.7 in., measured diagonally in the rows. Length of bolster, 1.6 in.; width, 0.4 in. Vascular scar above the middle. Surface of (decorticated) specimen striolate.

C. L. Herrick.

Socorro. N. M.

THE VARIATIONS OF GLACIERS. IX.[1]

THE International Committee on Glaciers met in Vienna last summer, and the retiring president, Professor S. Finsterwalder, presented a report to the International Congress of Geologists, of which the following is a brief summary:[2]

Although the committee has been at work only nine years, a time too short for very general results, still we can say that the thirty-five years' period which Brückner found in the variations of the Alpine glaciers applies also to glaciers in other parts of the world. It is also probable that there are longer climatic periods than this whose course is very complicated; moreover, the individual character of the variations of special glaciers is, without doubt, dependent upon the topography of their basins. We therefore have to do with variations of a very complicated character, as they depend both upon climatic changes and upon individual characteristics. But we can say, in general, that the dominating tendency of glaciers at the present time is to retreat. There are many exceptions to this rule, the reasons for which are not understood. The Mont Blanc group showed some tendency to advance in the eighties, and within the last twenty years this advance has been transferred to the most easterly Alps, though not advancing regularly over the intervening regions.

The Vernagtferner presents the most remarkable phenomena. This glacier increased 400^{m} in length between 1897 and 1902, which is not so extraordinary for it; but, in addition, the velocity of flow in a certain profile near the end increased from 17^{m} to over 250^{m} per year, and then suddenly within one year sank back to 80^{m}. The Vernagtferner is unique in other ways, and the careful study of its characteristics will add greatly to our knowledge of glaciers.

Professors Forel and Richter have offered explanations of the

[1] The earlier reports appeared in this JOURNAL, Vol. III, pp. 278–88; Vol. V, pp. 378–83; Vol. VI, pp. 473–76; Vol. VII, pp. 217–25; Vol. VIII, pp. 154–59; Vol. IX, pp. 250–54; Vol. X, pp. 313–17; Vol. XI, pp. 285–88.

[2] *Comptes rendus du Congrès géologique international de Vienne* 1903, pp. 161–69.

apparent irregularities of glacier variations. The increase in snowfall in the reservoir results in a thickening of the upper part of the glacier, which thickening then progresses down the glacier, somewhat like a wave, more rapidly than the ice itself. The ice thus advances faster than it melts, and the glacier is pushed farther down its valley. When the supply in the reservoir diminishes, the pressure from behind also diminishes, and the ice moves less rapidly and melts back.

Professor Finsterwalder then takes up the study of an ideal glacier, subject to periodic variations of thickness at the névé line, and subject to uniform melting along its whole length; and finds a mathematical equation which represents the changes in thickness and length which the glacier undergoes. Although these conditions are not exactly those which a glacier experiences, still they are near enough to give results which correspond fairly well with what is actually observed. The solution of the equation shows that the glacier in advancing takes a steep slope in front and moves with considerable velocity, and during the retreat takes a very gentle slope in front and its velocity is much diminished. The variation in thickness at the névé line produces a much greater relative variation in the length of the glacier, and the change at the end occurs later than the change at the névé line. Under these conditions the glacier advances slowly and retreats rapidly. This is in contradiction to experience, as glaciers usually advance rapidly and retreat slowly. This contradiction probably comes from the fact that we have assumed a uniform variation at the névé line, which, however, is probably not at all regular, but makes a rapid increase and a slow diminution. If now we introduce a variable rate of melting, and assume that it has the opposite phase to the variation of thickness at the névé line, we find the variation in length increased and the state of minimum existing for a longer time, which Forel has described as characteristic of glaciers. It thus appears that the Forel-Richter theory is, in general, upheld by mathematical analysis; but there are many peculiarities which are still unexplained. In the observations of the Vernagtferner glacier very great variations of velocity were found without corresponding increases in thickness.

Lately Hess has shown that ice yields more rapidly to a given

force as the time of application of the force increases. This might explain some of the difficulties, but many difficult questions of glacier physics arise in this connection.

The International Committee serves as a natural point of union for all investigators of glacier phenomena, and is doing good work in encouraging glacier studies.[1]

The following is a summary of the eighth annual report of the International Committee on glaciers:[2]

REPORT OF GLACIERS FOR 1902.

Swiss Alps.—Of the ninety-five glaciers which are being observed, seventy-eight were measured in 1902. The great majority of them are in a state of recession, and it is probable that the 680 other Swiss glaciers are receding also. The recession is therefore general, though there is a slight tendency this year to advance, shown especially among the glaciers in the southwest Bernese Alps. The little glacier of Boveyre, which has been advancing for ten years as a result of a great increase in material due to an avalanche, has begun to retreat.[3]

Eastern Alps.—On the south side of the Ortler, two glaciers have retreated $3.5–11^m$; one has probably made a slight advance. In the Silvretta group three glaciers show a retreat of $400–500^m$ since the last maximum in 1850–60. In the Oetzthal the Vernagtferner, which last year showed an advance of 50^m and a remarkable increase in velocity of from 210^m to 240^m, has suddenly decreased its speed to not more than one-third of its highest value; it has, however, advanced 20^m, and has swollen in its lower part. Its neighbor, the Guslarferner, has been stationary for many years.

[1] Professor Harry Fielding Reid, of Baltimore, was elected president of the committee for the ensuing three years, and M. E. Muret, of Lausanne, was re-elected as secretary. Professor Nathorst retired from the committee and was elected a corresponding member. Baron G. de Geer was elected to succeed him as representing the Arctic regions. Colonel J. von Schokalsky had already been elected to succeed the late Professor J. Mouschketow, who took such an active part in the work of the committee. The following additional corresponding members were elected: Professor Dr. A. Blümcke, of Nuremberg;; Professor Dr. Hans Hess, of Ansbach; Professor Dr. A. Penck, of Vienna; and Mr. George Vaux, of Philadelphia.

[2] *Archives des sciences physiques et naturelles*, Vol. XV, pp. 661–77; Vol. XVI, pp. 86–104.

[3] Report of Professor *Forel* and M. *Muret*.

Borings have been made in the Hintereisferner to determine its thickness. It has been completely pierced at a distance of 1,860^{m} from the end, where a thickness of 152.8^{m} was found. This glacier has retreated 94^{m} in the last eight years, and its velocity of flow has been reduced 25–30 per cent. Hochjochferner, near by, has retreated only 1^{m}, but has become somewhat thinner. Diemferner deserves special attention; it has advanced 30^{m} in the last two years, and 144^{m} since 1893. It has suffered a considerable change in form, and in the upper regions its sides very nearly reach the top of the old moraines.

In the same general neighborhood seven glaciers have retreated 6–20^{m} since 1891; and six others have retreated 21–90^{m} since 1899; two of these were advancing a few years ago. One glacier observed in the Stubai group is in continued retreat. In the Zillerthal the Schwarzenstein glacier is retreating, but more slowly than last year. The Horn Glacier has ceased to advance and has retreated 4^{m}, while the Waxegg has advanced 14^{m} on the average, and at one point 38^{m}. In the Venediger region eight glaciers show recessions of from 2–17^{m}. The Krimmlerkees, which shows the greatest retreat this year, was advancing last year.

In the Glockner group two glaciers have retreated 7–11.5^{m}, while the Pasterze is stationary.

In the Sonnblick group three glaciers show recessions of 5–20^{m} in two years. The Krummelkees, which advanced 7^{m} from 1899 to 1901, has been stationary since then.

In the Ankogl group two glaciers are retreating, but only half so fast as last year. On the other hand, the great Elendkees has changed its slight decrease of last year to a slight increase this year.

On the whole, the retreat is more rapid this year than in preceding years; nevertheless, a few glaciers are still advancing. We must mention that the Gepatschferner has been steadily retreating since 1886, when exact measures began.[1]

Italian Alps.—The Marmolada Glacier has retreated very considerably during the last forty years, though we cannot say what it is doing at the moment. The upper regions show signs of diminishing, but the growth before 1883 was made evident by the ice

[1] Report of Professor *Finsterwalder.*

closing up a grotto used as a sleeping-place by the Italian Alpine Club. This grotto remained closed from 1884 to 1900. The Cristal, Sorapiss, and Kellerwand Glaciers have all retreated from a fraction of a meter to 3^m. The snow-fields of Monte Cavallo show a considerable increase in size. The Lys Glacier, Monte Rosa, has retreated about 25^m, shows a marked change in its form, and reveals newly deposited moraines. In general, the retreat of the Italian glaciers has continued, but the snowfall has increased.[1]

French Alps.—Many glaciers have been observed under the direction of the French Committee on Glaciers, with the following results: On Mont Blanc the Bossons has greatly diminished; and the Mer de Glace, stationary for some time, now shows a marked recession.

In the Maurienne eleven glaciers are retreating; one has been stationary since 1892. The Glacier des Sources de l'Arc has retreated $1,250^m$ horizontally and 300^m in altitude since 1873. In the Grandes Rousses the Glacier des Quirlies has retreated about 25^m since 1899, and the Grand Sablat about 35^m. The Glacier de la Selle has retreated $600–800^m$ in the last thirty years. The Glacier des Étançons has retreated greatly, probably 100^m in the last fifteen years. Of its two tributaries which are now separated, one is advancing and the other is retreating.

The Pyrenees.—The advance of the end of the nineteenth century has affected the Glacier de Vignemale, which has inrceased notably in thickness, though it has not advanced. The glaciers, in general, are distinctly retreating. Of the twenty observed, fifteen are retreating, and the others are either stationary or possibly growing, although none show any real advance from 1901 to 1902.[2]

Scandinavian Alps: Norway.—The summer of 1901 was particularly warm in Norway, so that the glaciers melted rapidly, and the snow-fields diminished to an extent never before seen. Many glaciers were retreating, and the glacial streams were much higher than usual. On the other hand, during the summer of 1902 the snow remained very late. Several glaciers of Galdhötind advanced $15–20^m$, and several receded, perhaps as much. On August 11, the glacier lake of Mjölkedalsvand was suddenly emptied and caused an inundation. Two glaciers near Olden are retreating.

[1] Report of Professor *Porro*. [2] Report of Professor *Kilian*.

In the neighborhood of Folgefon several glaciers were retreating rapidly in the summer of 1901, whereas in 1902 they were advancing.

Sweden.—The Mika Glacier has advanced 5^{m} since 1901, and the Solta 20^{m} since 1900. The Skuova has apparently been stationary since 1897.[1]

Polar regions.—An expedition was sent to Greenland to study the inland ice between latitudes 68° 30′ and 69° 20′. Surveys of the Jakobshavn Fjord and the border of the inland ice to the south were made on a large scale. Photographs were also taken from marked points which may be used for future comparison. All the glaciers of the Jakobshavn Fjord are notably retreating; the rocks for 5.5^{m} above the present surface of the large glacier are entirely free of lichens, and the tongue of the glacier is 4^{km} shorter than in 1883. The small glaciers flowing from the tributary fjords of the Jakobshavn show a similar, but smaller, retreat. Farther south, near Orpigsuit, the edge of the inland ice seems to be retreating, as the rock immediately above it is free of lichens and is covered with fresh striæ. Photographs of the nunataks were taken which will serve to determine future variations.

The Swedish expedition to the South Pole visited Royal Bay in the Island of South Georgia. Ross Glacier, which had retreated, according to the German South Polar Expedition, 800–900^{m} between 1882 and 1883, has since then advanced to the point where it stood in 1882.[2]

Himalaya.—The Taschiny Glacier in Kashmir was retreating in 1875 and advancing in 1886. Some small glaciers in the Panjal Range were retreating before 1884 and advancing slightly some years later. In the Nun Kun the glaciers were advancing in 1902.

In the Karakorum Range several glaciers in Schigar Valley advanced for eight or ten years before 1895. In the Saser-Nubra Mountains a slight advance took place in 1896.[3]

Caucasus.—The four glaciers on Mount Kazbek which have been retreating for some time have become stationary, and great accumulations of snow seem to indicate the beginning of a new advance. The summit of Kazbek, which in 1900 was almost free of snow, is now covered to a considerable depth. In the valley of the Guisel-

[1] Report of Dr. *Oyen.* [2] Report of Dr. *Steenstrup.* [3] Report of M. *Chas. Rabot.*

Don the Djimara Glacier is still retreating, as are also two glaciers in the valley of the Ouroukh. The Mayl Glacier, on the northern slope of Mount Kazbek, was the scene of two terrible outbreaks which destroyed the baths of Kermadon in July, 1902. Two avalanches, originating in seven large snow-fields, came down a lateral gorge, and then passed over the surface of the glacier, following a course six miles long. The slopes of the mountains are not steep enough to cause this catastrophe, and it is probable that it was induced by an earthquake.

Siberia.—A number of small glaciers exist near the sources of the Oka River in the mountains southwest of Lake Baikal. Some of these were described by M. Radde in 1885. They are at present much smaller than they were then, and one of them seems to be on the point of disappearing. The Alatau or Kuznezk Mountains, 200 or 300 miles north of the Altai, do not contain any glaciers at present, but they show traces of former glaciation in the smoothed rocks and large moraines. In the Alatau of Sungaria there are many glaciers; those on the northern slope being generally larger than those on the southern. Two of the former have been surveyed. The mean height of the peaks in this portion of the range is about 13,000 feet. There are many glaciers in the Tyan Shan mountains which are rarely visited. The peaks of this chain have altitudes of from 16,500 to 17,500 feet; a new determination of the height of Mount Khantengri makes it 22,600 feet. Some of these glaciers are in a marked state of retreat; others do not indicate any definite variations. It seems in general that, if the glaciers are decreasing, there must be shorter intervening periods of growth, at least for some of the glaciers.[1]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1903.[2]

In May, 1903, the Muir Glacier was visited for the first time since the earthquake of 1899. Mr. C. L. Andrews, deputy collector of customs at Skagway, and Mr. Case went from Skagway to the Muir Glacier in an open boat, photographed the end of the ice,

[1] Report of M. *Schokalsky*.

[2] A synopsis of this report will appear in the *Ninth Annual Report* of the International Committee. The report on the glaciers of the United States for 1902 was given in this JOURNAL, Vol. XI, pp. 287, 288.

and showed by a map the changes which have taken place there. They found that the ice-front had retreated to a distance of from 3 to $3\frac{1}{2}$ miles from its former position, and almost the whole inlet was covered with floating ice very closely packed together. The ice-front now passes from the base of Mount Case northwesterly to the two small nunataks opposite, which have become united into one by the lowering of the ice. It then passes southwesterly to the corner of the large nunatak which separates Morse Glacier from the Muir. An area of $4\frac{2}{3}$ square miles has thus been taken from the glacier and added to the inlet. An area of 9 square miles of the inlet is closely covered with floating ice. The amount of ice which has been broken off from the glacier—if we assume an average thickness of 700 feet, which is probably not far wrong—amounts to about 91,000 million cubic feet. This is about fourteen times the amount formerly discharged annually into the inlet.[1]

The ice forms a terrace along the eastern side of the mountains, and Dirt Glacier ends as an independent tide-water glacier. Morse Glacier, which had already become an alpine glacier, separated from the Muir, no longer has its valley closed up by the latter's ice.[2]

The new ice-front is composed of two parts. The eastern part from Mount Case to the nunatak consists of ice which is practically stationary, whereas the western part receives all the active flow of the glacier. This portion does not differ materially in breadth from the old ice-front, and receives practically all the ice which was formerly discharged into the inlet. It stands up as a vertical wall probably about 200 feet above the water. In 1890 the surface of the ice where the glacier now ends was 500–600 feet above sea-level, so that this surface has been lowered 300–400 feet. The fact that the ice stands up as a vertical wall makes it probable that the water is fairly deep at this point, though probably not as deep as at the old ice-front. If this is so, the velocity of the ice near the present end is probably a little greater than near the old end, as the section is somewhat less. This causes a tendency to advance, but the position of the end will probably remain almost stationary for some time; for if it advances materially beyond its present position, it will find no

[1] "Studies of Muir Glacier," *National Geographic Magazine*, Vol. IV (1892), p. 51.

[2] C. L. Andrews, "Muir Glacier," *ibid.*, Vol. XIV (1893), pp. 441–45.

support on the east; it will broaden out, and will offer a longer line for breakage. If, on the other hand, there should be any material retreat, the ice-front would again become longer, resulting in still more rapid retreat, until, perhaps, the glacier withdraws above tide-level.

There are eight glaciers of considerable size within easy reach of Skagway. These glaciers have been under observation by Mr. Andrews, who expects to continue to observe them. They are all retreating rapidly. Denver Glacier melted back 40 feet in two months in the summer of 1903. The "S" Glacier and the Upper Glacier have been retreating at the rate of 30 or 40 feet a year since 1898 (*Andrews*).

The Mendenhall Glacier near Juneau retreated at the rate of 40 or 50 feet annually between 1892 and 1901. Immediately bordering its sides and end the ground is free of vegetation, but the shrubs and trees gradually increase in extent and size as we go farther from the glacier, either down its valley or up the mountain side. This increase in the age of the trees indicates the rate at which the glacier has retreated. It is very remarkable how rapidly trees have grown in this region, attaining a thickness of nine inches in twenty-five years and of nearly two feet in one hundred years[1] Mr. Fernow has also noted the remarkably rapid growth of trees at the entrance of Glacier Bay, where trees only forty or fifty years old were 36 inches in diameter and 80 feet high.[2]

Throughout Oregon and Washington the last three years have been marked by excessive precipitations, and the snowfall of last year seemed to be the greatest of the three; but there is no evidence that this has yet resulted in the advance of the glaciers. Mount Baker is an interesting mountain, but it has received very little attention. It was ascended last summer by Mr. C. E. Rusk, who writes me that there are about ten glaciers on the mountain. Two of these, which he had the opportunity to examine, showed signs of marked retreat in recent years.

The Eliot Glacier on Mount Hood has retreated slightly since

[1] MARSDEN MANSON, "Forest Advance over Glaciated Areas in Alaska and British Columbia," *Forestry Quarterly*, Vol. I (1903), pp. 94–96.

[2] See *Harriman Expedition*, Vol. II, pp. 249–52.

1901. (*Langille.*) The glaciers on the south side of Mount Hood also show evidence of retreat during the same interval. (*Montgomery.*)

There are two or three glaciers on Mount Jefferson, but we have no evidence as to their variations. The peaks of the Three Sisters surround a large amphitheater five miles wide, which opens toward the east and formerly held a large glacier, but this has shrunk so much that it has now broken up into four small glaciers. There are three others on the outer slopes of the mountain. The moraines of the glaciers in the amphitheater stand up 30 or 40 feet above their surface. They are still fresh and free of vegetation, showing that this diminution of the ice has taken place in comparatively recent years. The reduction in thickness of the ice seems to be more marked than the reduction in length. Ice still remains under the moraines, which is a further indication of the short time since they were formed. The double crests which some of these moraines present are ascribed to the melting of the ice under them. One of these glaciers showed in its Bergschrund projecting layers of ice separated by layers of dirt similar, on a small scale, to the projecting layers of ice found at the end of Greenland glaciers.[1] In the present instance, however, these projections are not ascribed to shear, but to differential melting; for where the snow is shaded from the sun the projections do not exist. (*Russell.*)

Comparison of photographs of Lyell Glacier in California taken in 1883 by I. C. Russell and in 1903 by G. K. Gilbert show only very slight recession, whereas the McClure Glacier, close by, has suffered a marked retreat during the same interval. (*Gilbert.*) This difference may be due in part to the shapes of the two glaciers, Lyell being much broader than it is long, whereas the McClure presents a definite tongue.

Professor LeConte has found a new glacier just below the eastern precipice of Mount Jordan, in northern California, and thinks that there are other small glaciers along the eastern slope of the Sierras in this neighborhood. There has been less snow in the Sierras

[1] I. C. Russell, "Glacier Cornices," Journal of Geology, Vol. XI (1903), pp. 783–85.

of California this year than for many years past, and probably all the glaciers are retreating. (*LeConte.*)

The Chaney and Sperry Glaciers in Montana show a marked retreat. The former, though a small glacier, has retreated 200 yards or more in the last eight years. (*Chaney.*)

The snowfall on the Arapahoe Glacier in Colorado was unusually small in 1902. In 1903, however, it was unusually large, and seems to have produced a noticeable effect on this little glacier. The ice is somewhat thicker and the front slope of the glacier steeper, but there is no apparent change in length, except at two points where streams have effected a slight recession. From September, 1901–2, the precipitation was below normal and the temperature above normal at the Weather Bureau stations nearest to this glacier, whereas it was just the reverse from 1902–3. Silt was found on the moraines similar to that found last year, and as it is impossible to suppose that the glacier has advanced over the moraine and retreated again within a year, the former explanation of this silt, which required rather violent fluctuations of the glacier, must be abandoned. It is probable that the silt is due to dust blown from the mountains upon the snow and left on the moraine when the snow melted. This is a more satisfactory explanation, but it shows nothing with regard to the glacier changes.[1]

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March 17, 1904.

NOTE.—Since the above report was written, the third volume of the Harriman Alaska Expedition, on *Glaciers and Glaciation*, has appeared. It is written by Mr. G. K. Gilbert, and is a valuable contribution to our knowledge of the Alaskan coast glaciers. Mr. Gilbert collates all information regarding the variations of these glaciers up to 1899, and adds the observations made by himself and by other members of the expedition. The positions of the ends of many glaciers are shown by pictures and maps. The glaciers discussed are too numerous to be named here, but we must mention the general fact that the glaciers of Glacier Bay and of Disenchantment Bay show very great recessions during the last hundred

[1] JUNIUS HENDERSON, "Arapahoe Glacier in 1903," JOURNAL OF GEOLOGY, Vol. XII (1904), pp. 30–33.

years, whereas those of the southwestern slopes of the Fairweather Range and those of Prince William Sound have quite lately been as extensive as they have probably been for several centuries. Mr. Gilbert makes some general suggestions of a theory to explain such curious anomalies. He also presents clearly the very striking evidence which the topography of the Alaskan coast offers in favor of the power of glaciers to erode their channels. The volume concludes with a theoretical discussion of the influence of the sea on the pressure which tide-water glaciers exert on their beds below sea-level.

FAREWELL LECTURE BY PROFESSOR EDUARD SUESS ON RESIGNING HIS PROFESSORSHIP.[1]

In the last lecture we occupied ourselves with the structure of South America. We saw that the earlier volcanic occurrences are restricted entirely to the Cordillera of the Andes, but that in the course of their appearance there are long interruptions.

We have therefore arrived at the close of our hasty survey of the earth's entire surface, and today we will review the events which have been set forth during the last two semesters. The present lecture, moreover, also closes my active life as a professor, and I stand at the end of a career of teaching at this university, which I have been permitted to enjoy for eighty-eight semesters. Before I take up the short summary mentioned, I believe it suitable to say a few words in regard to the changes which our science has undergone during this long period.

My collegiate work as lecturer on general paleontology was begun October 7, 1857—two years before the appearance of Darwin's book, *The Origin of Species.*

It is well known that in the eighteenth century prominent thinkers, as Leibnitz, Herder, and others, properly recognized the connection and unity of all organic life. But, at the beginning of the nineteenth century, Cuvier, essentially by means of the fossils of the chalk of Montmartre, was able to present the surprising evidence that there had lived on the earth genera of animals which today are wholly extinct, and that similar changes have again and again occurred in the animal kingdom. He thus concluded that there had been repeated revolutions. In this he was followed by the great majority of inquirers, and at that time—the year 1857—everyone was completely under the influence of Cuvier's views. Personally, a paper by Edward Forbes, on the influence of the glacial period on migrations, had a great effect on me; the article merits reading even to this day.

[1] Given July 13, 1901, in the Geological Lecture Hall, Vienna University; taken stenographically by Mr. H. Beck. For the original lecture, in German, see *Mitth. Pal. u. Geol. Inst.*, Universität Wien, 1902, pp. 1–8. Translator, Charles Schuchert.

After the appearance of Darwin's book, there occurred a great and general change of view in all branches of biology. In fact, outside the great discoveries of Copernicus and Galileo, there cannot be cited another example having so deep an influence on the general opinions of naturalists. Darwin was not the first to conceive and pronounce upon the unity of all life; but that he was able to produce stronger proofs and to direct the trend of thought constitutes his undying fame.

In the field of paleontology the consummation of this change did not, of course, go on so simply and, at least with us, so entirely in accordance with the views of Darwin as one is apt to imagine. The Darwinian theory of the variability of species was essentially based on selection and related appearances. Paleontology, however, teaches otherwise. It teaches that the terminology for single divisions of the stratified terranes, characterized by their fossil remains, finds application over the entire earth. Therefore from time to time there must have occurred, in some way, general changes affecting the entire physical condition of the world. Nor is there seen a perpetual and continuous changing of organic beings, as would be the case through the constant influence of selection. On the contrary, there are entire groups of animals appearing and disappearing. Darwin sought to explain this by means of gaps in our knowledge, but today it is known that these supposed gaps possess too great a horizontal extension.

There now arises the thought that the changes in the outer conditions of life have a controlling influence. I may here state that on this question there was some correspondence between Darwin and our widely mourned Neumayr, and that Darwin in no wise took a dissenting stand against the objections. In this connection it is most remarkable that the great and general knowledge of paleontology which I have just indicated, should apparently have made upon so great a mind as Darwin's less of an impression than those small lines of variation noticed in certain fossil fresh-water snails, as, for example, in *Valvata* or *Paludina*.

Here and there conditions are combined which permit somewhat closer analyses of the relations of this subject. This for instance, is the case in the superposition of the Tertiary land faunas of Europe,

more particularly of Vienna. Here one recognizes the following: Living beings are dependent, on the one hand, on certain outer physical circumstances, as climate, moisture, etc.; on the other hand, they also are mutually and socially dependent upon one another. Every living province—or, as it is usually expressed, every zoölogical province—forms, as it were, an economical unity in which for so many flesh-eaters there must be so many plant-feeding food animals; for so many plant-feeders, so many food plants; honey-sucking Lepidoptera presuppose flowers; for insect-feeding song-birds a certain number of small insects are necessary, etc. The disturbance of one member of this unity can possibly destroy the balance of the whole.

According to all appearances, such disturbances have occurred from time to time in land faunas, and they may have been of very diverse kinds. Then again an entire fauna is seen to vanish over all Europe, or over a still greater region, and a new fauna comes in to take its place. This new fauna nevertheless always has a more or less strongly vicarious relationship to its predecessor; it is clearly a variation of the former, probably in the main a resulting adaptation to changed conditions; and even if the sequence of strata were completely unknown, one could readily discern which was the first, the second, or the third fauna.

Besides this, the numerous phylogenetic lines which unite nearly all the great groups of fossil animals; or the unity in the developmental nature of single organs, as the extremities; or the general superposition of gills and lungs; or the rows of striking harmonies that exist between the development of certain groups of animals, and of single individuals of these groups—all indicate with certainty the correctness of the Darwinian basal idea, namely, the unity of life.

Stratigraphic geology and paleontology show that the evolution of organic life was probably never completely interrupted, but that it did not go on in a uniform manner. Disturbances have occurred. The struggle for existence continues; yet it is only of secondary importance. Single very old types, as *Hatteria* (*Sphenodon*), have continued to maintain themselves to our day with but slight changes.

Allow me now to speak of a few tectonic questions.

When I began my collegiate work, there prevailed, especially in

Germany, the idea that mountain chains were built symmetrically; one group of oldest rocks formed the lifted or lifting axis, and upon each side were arranged younger rocks in parallel zones. Thus, you will still find in my own writing on the substructure of Vienna, in the year 1862, a presentation of the Alps as symmetrical mountains.

Of course, this idea did not prevail without objections. At nearly every gathering of German naturalists at that time, the old Bergrath Dücker arose to protest against it. No one listened to him. With Schimper it was the same. The authority of Leopold von Buch, who expressed himself for symmetrical construction, remained unshaken. Then Leopold von Buch died. Upon this primary question of modern geology you will find no explanation for the origin of mountains in the leading text-books of that time, as, for instance, Lyell's justly celebrated *Principles of Geology.*

For the investigation of this problem no part of Europe was more advantageously situated than Austria. There the land is arrayed before us in unusual variety. Hardly anywhere in Europe are tectonic contrasts so plainly presented—contrasts between the Bohemian Mass and the Alps, between the portion of Russian table-land beneath the Galician plain and the Carpathians, the peculiar connection of Alps and Carpathians, the continuance of the Turkestan depression over the Aral Sea into the depression of the Danube and to Vienna, and much besides. In the year 1857 the idea was still often maintained that the deposits found in the eastern Alps did not occur at all outside of the Alps, so great were the difficulties which the application of the accepted stratigraphic divisions of England and south Germany bore to the strange occurrences in the Alps themselves.

Soon, however, it was recognized that in the Bohemian Mass the stratigraphic sequence was far less complete than in the adjoining regions of the Alps, and that in Bohemia particularly there is an extraordinary interruption of marine deposits extending upward into the Middle Cretaceous, whereas in the Alps all these great epochs are represented by marine strata. This same transgression of the Middle and Upper Cretaceous shows again in Galicia, then far into Russia, on the other side of the French Central Plateau, on the Spanish Meseta, in large parts of the Sahara, in the valley of the Mississippi, and northward over this region to the vicinity of the Arctic Sea, in

Brazil, finally on the shores of central and southern Africa, in east India; and, in fact, over such extraordinarily vast regions that it became impossible longer to explain such transgressions of the sea, according to the older views of Lyell, by means of the elevation and depression of continents.

Through this and similar observations the newer idea has recently come into prominence that some general change must have occurred either in the shape of the hydrosphere or in its entire volume. It was seen that by the forming of a new oceanic depth, due to sinking, a certain amount of the hydrosphere was drawn off into the new depression, and that at the same time there appeared to be a general land elevation, or, more correctly, there must have resulted a general sinking of the beach lines. The older view of the numerous oscillations of the continents has also given way more and more to the teachings of marine transgressions, and through the denudation of continents, a more exact examination into the actual mountain movements has become possible.

If one were to assert that the Alps are folded, but that the Bohemian Mass is not, and that because of this there has resulted a damming up, then this assertion would not be exact. The Bohemian Mass is also folded, and there is at present no known portion of the earth's surface of which at least the archaic base is not folded. The difference, however, consists in this, that the folding has ended early at certain places; at others it has continued into a later or very late time, and possibly has also continued with a change in the groundplan.

In this respect central Europe shows a quite peculiar arrangement. The oldest folding is seen in the gneiss of the western Hebrides. Younger and of pre-Devonic age are the folds of the Caledonians, which can be traced down to Ireland. On these, farther south, are ranged the Armoricanian and Varischian folds, which embrace southwestern England, Normandy and Brittany, the Central Plateau, the mountains of the Rhine, and the Bohemian Mass, inclusive of the Sudetes. Its principal folding was accomplished before the close of Carboniferous time, but minor movements of various kinds have followed. The Alps and Carpathians even underwent decided folding in the Miocene. Each part has moved northward toward the pre-

ceding, or toward the horsts, in which the earlier member was dissolved by sinking, and thus Europe has resulted through a succession of younger and younger folds.

Meanwhile, more and more light came regarding the strange development which certain Mesozoic deposits, particularly the Triassic of the Alps, show when compared to the north-lying lands, as Würtemberg or Franconia. The observations in Asiatic highlands, especially in the Himalayas, taught that this type of Triassic development has a very wide distribution toward the east; and it even became possible to prove that directly across present Asia, from the existing European Mediterranean to the Sunda Islands, there once extended a continuous sea. This sea has, as you know, received the name Tethys. The old continent along its southern side was named Gondwana Land, and that on its northern side, Angara Land. The present Mediterranean is a remnant of Tethys.

This Mediterranean, however, consists of a series of areas of diverse construction, and we have had opportunity to convince ourselves that, since Middle Tertiary time, first a portion was separated, as, for instance, the Danube plain, then a portion was added, as the Ægean Sea.

The progress of geological research during the last ten years, however, has been so extremely great that a far more extensive knowledge of the seas has become possible. They are of different kinds. We examine a world-map, and thereby, in accordance with oft-repeated warning, seek to guard against the deception which the distortion of Mercator's projection so easily produces. We see that, with the exception of the two Chinese rivers, Yang-tse-kiang and Hoang-ho, hardly another great stream finds its way to the Pacific Ocean. All waters of the continents flow toward the Atlantic or Indian Ocean. Many years ago the Russian General von Tillo drew on a little map the watershed of the earth, and showed how surprisingly small an amount of fresh water the Pacific receives.

These two oceanic areas differ also in a feature of far greater importance. At the beginning of these lectures I noted the remarkable fact that from the mouth of the Ganges eastward to Cape Horn the continents are bounded ocean-ward by long arcuate mountain ranges, all of which appear to be moving toward the Pacific Ocean.

When, however, one follows the coast from the mouth of the Ganges westward, and again to Cape Horn, totally different conditions are met. Disregarding the bending of the mountains at Gibraltar and vicinity, which the American Cordilleras in the Antilles also show—at both places, as you know, folded mountain chains do approach the Atlantic area, but they bend backward as if held back by some secret force—one sees encircling the Atlantic and the Indian Oceans only similar amorphous coast lines, namely, such as are in no wise predicated by the structure of the lands. Therefore we have distinguished a Pacific and an Atlantic type of coast.

We can go still farther. In whatever direction one proceeds from the land to the Pacific, an unfolding sequence of marine series is seen. If one goes from the wide Archean areas of South America, on which lie horizontal Paleozoic sediments, toward the west, in the Andes are found marine beds of the Jura, the Lower Cretaceous, also the Middle and Upper Cretaceous. It is the same if one goes from the old Laurentian Mass in Canada westward toward the sea. This is also the case in Japan, etc. From the foregoing we may conclude that the Pacific is of very ancient origin, and that it has existed for an extraordinarily long time.

With the other oceans it is different. When one nears the Indian Ocean, horizontally disposed marine beds are met with, not folded strata as in the Pacific area. These, however, do not begin with the Trias, but in east Africa as in western Australia start with the Middle Jura, and in Madagascar with the Middle Lias. Similarly, on the shores of the Atlantic Ocean horizontal non-folded strata are found, and these, in west Africa as in North America and Brazil, begin with the Middle and Upper Cretaceous. From this we conclude that the Pacific Ocean is older, the Indian Ocean younger, and the Atlantic Ocean essentially still younger.

I have mentioned yet another ocean, Tethys, which in Mesozoic times lay across present Asia, and whose remnants constitute our Mediterranean. The entire area of Tethys is laid in folds, and from the Pacific Ocean to the Caucasus throughout these folds are also moving southward; their margins in the south are overthrusted; the entire province of the sea is crushed from the north, and even remnants of the old southern foreland—the Gondwana Land, or the

Indian peninsula—are included within this folding. You have heard that Kinchinjinga and its neighbors, the highest peaks of the earth, though within the folds of the Himalayas, still have, so far as known from their foothills, the stratigraphic sequence of Gondwana Land.

We will now take a glance at the distribution of the lines of folding on the earth's surface. In the region of Lake Baikal lies an extensive, somewhat crescentically arranged mass of very ancient Archean rocks. It is folded, with a nearly northeast strike in the east and a northwest strike in the west, and the folds are of pre-Cambrian age. This old strike locus or vertex embraces Sabaikalia, northern Mongolia, and the East Sajan. Farther northwest there is developed another, younger vertex, or a second center of folding—the Altai. From this second younger locus proceeds an extraordinarily great system of bow-shaped folds, which, in an almost incomprehensible manner, embraces the entire Northern Hemisphere. The Altai encircle the old vertex, and its bows repeat themselves in the east from Japan and Kamschatka to the Bonin Islands. Toward the west they form the broad ranges of the Tian-shan and Bei-shan. Their southeastern branches appear in the bows of Burmah. In front of them to the south lie the marginal bows of the Himalayas—the Iranic; and farther along, the Tauric-Dinaric bows. They press over the Caucasus to Europe, and form here the two previously mentioned chains of folds.

These two chains of folds are themselves preserved in different ways. The one, older, embracing the Varischian and Armoricanian folds, is first discernible in Mähren. It reaches the Atlantic Ocean in southwestern Ireland and Brittany, and disappears as a Rias coast. Years ago, however, Marcel Bertrand called attention to the fact that such a broad and mighty mountain system—on the Atlantic coast it is as broad as the bows of the Himalayas—could not possibly suddenly end here, but that in all probability it is continued to the other side of the ocean in the Rias coast of Newfoundland. As you have heard, Marcel Bertrand accordingly continued the Armoricanian primary lines directly across the ocean to the Appalachians.

Of the Appalachians, however, it has been learned in recent years that they are far longer than was formerly believed. They form a bow which is not, as in the Asiatic and European chains,

folded toward the convex side, but toward the concave side, first westerly, then northerly, and continues west of the Mississippi into the Washita Mountains.

The second or younger type, the Altai, strikes with decided flexing, narrowed through older horsts, from the Balkans to the Carpathians and the Alps, and at Gibraltar the latter join those bows of the western Mediterranean that are completely reversed.

Let us return once more to North America. As we have heard, the American term as Laurentia the wide Archean area which embraces the region of the Hudson Bay, middle Canada, and the central part of the United States. The Appalachians to the east and south of this mass, as we have seen, have a concave strike, are folded toward Laurentia, and vanish in the Washita hills. West of Laurentia, also, it is similar. It could have been shown that the Cordillera, whose connection with northern Asia has of course not yet been established, is, on its eastern side, in Canada, also folded toward Laurentia. It, too, bends toward the south with a more and more concave strike; continuing through Mexico, it is folded to the northeast, and then part of its folds finally turn toward Cuba and in the direction of the Antilles.

Thus on both sides is North America encircled by concave-striking chains of folds. It is as if the folds extended away from Asia and toward Laurentia. This entire grand phenomenon may be illustrated by a comparison. By the eruption of Krakatoa the oceans were moved; long waves proceeded from the place of eruption, traveled around the entire earth, and met themselves on the other side of the sphere. This is merely a comparison, not an explanation.

In the Southern Hemisphere the state of things is wholly different. For some time it has been known that in East India and South Africa, during Permian and Trias time, there flourished identical land floras—the Gondwana floras. Accordingly, it is concluded that these two continents were once united, and the area was named Gondwana Land. Later such floras were also found in Australia; then in the Argentine Republic. Thus it spread around the south. But the conclusion drawn from this as to the continuity of so great a continent was shattered by the circumstance that not only the

characterizing plants of Lower Gondwana, but, in addition, the South African occurrences of associated animals, were also found in the Permian deposits of Perm in north Russia.

What then results is an exceedingly similar distribution of land plants and land animals of that time, and a great continent in the south; yet immediate proof of its continuity is lacking.

In fact, only on the Pacific margins of this supposed or actually united continent is it found that folding has taken place, and, indeed, in the east of Australia and the west of South America; while the intermediate Atlantic and Indian coasts are without younger folds. It is true that more recently, folding of pre-Carboniferous time has been described in South Africa, but in general the entire area between the western South American Cordilleras and the eastern Australian Cordilleras appears dead and unmovable. This is in contradistinction to the great diversity in movements of the Northern Hemisphere.

In general, these are the chains which we have sought to follow in detail in the course of these two semesters. The attempt toward a geometric arrangement of the mountain chains, which recently has been undertaken by distinguished specialists, finds, I fear, but little confirmation in actual occurrences. The tectonic lines that are met in nature tend generally at most to follow straight lines only in fissures or faults. The foldings, however, maintain themselves more like long waves, and they give way to the older horsts. This is seen more clearly in the youngest Alps, or that branch of the Altai trending toward Europe; the bows of the Banda Islands are similar.

I should now like to say a little about the conditions of life upon the earth. We have already spoken of the wide distribution of the land faunas and land floras of Lower Gondwana. Earlier types of Carboniferous land floras had spread themselves from the Arctic region to South Africa. The Culm flora is known in Europe, Mongolia, and Australia. Still more noteworthy is the fact that in the basalt streams of western Greenland there are interbedded plant layers of Lower and Middle Cretaceous, as well as of Tertiary times, and that during all this period there lived in this Arctic region first ferns and then leaf-bearing trees. In a word, in west Greenland

are seen occurrences of different times which throughout cannot be brought into harmony with the climatic conditions of the glacial period nor with those of the present; thus this entire younger epoch appears as an exception. One gets the impression that not at all times did there exist the present diversity of climate, and also that the diversity of life was not at all times a varied one. The great Indian land fauna of today, with its tigers and elephants, can be considered as an independent unity, but here and there it is accompanied by older Malayan remnants which increase the diversity.

Gentlemen, as you see by this attempted survey, I can point out only some of the various directions in which our studies may be continued, and there exist so many hundreds and hundreds of questions that all, even the keenest ambition, will find the portals open and may hope for satisfaction. New discoveries are in prospect for all conscientious inquirers.

In the course of the years I have seen and experienced much. In the beginning a man has honestly to endeavor with zeal, and with certain restrictions upon himself, to learn the detail; and sometimes the hair whitens before he is in a position to obtain a general view and to risk a first synthetic attempt. This first step to synthesis is, however, the deciding step in the life of the inquirer. Soon he notes that his judgment obtains more consideration among his colaborers; he becomes more careful and conservative with the same; and finally the hour arrives in which his soul is filled with the highest satisfaction, because he has been able to add to human knowledge some new view or a new fact—a feeling over against which everything naturally vanishes that the outer world is able to offer in acknowledgment.

Bulwer Lytton says in his novel: "When a man of great age is surrounded by children, he then sees at the end of his days, not a period, but only a comma." This applies in equal measure to the inquirer and to his students. This is my good fortune, which today becomes my portion.

Many have departed from us. The dumb tablets in our collection halls give their names, and it is our duty today to remember them gratefully. Stolizcka found his end on Kara-Korum, Lend on Kilima-ndjara, Foullon on Gaudalcanar; Rodler brought his death

germ from the Bachtyari Hills; we all think of Oscar Baumann with admiration.

I rejoice today with all my heart that I am enabled to greet, not a series of students, but generations of students, from the renowned gray-haired members of the Royal Academy to the young fellows with sharp eyes.

To the young ones among you I should at this moment like to say another word. The old ones know it already. In the course of these forty-four years much has occurred on the earth, but nothing at this time so penetrating, nothing so decisive for the entire culture of humanity, as progress in the natural sciences. Into all departments of human life and doings it has entered; it influences and changes our social conditions, our philosophical conclusions, our political economy, the strength of states, everything. He who will look closer, however, can perceive that, besides the natural sciences, the naturalist himself is coming more and more to the front, that his social significance is being recognized, and that the worth of his studies is being more valued.

Accordingly, the growing generation of inquirers has an increased duty, which consists in this, that the ethics of their personal life shall become more precise, so that, by the increasing influence of naturalists on all social and state life, the naturalist will also feel himself more worthy to take part in the guidance of intellectual humanity.

And now I have reached the comma. When I became a teacher, I did not cease to be a student; and now that I cease to be a teacher, I shall not cease to be a student so long as my eyes see, my ears hear, and my hands can grasp. With this wish, I therefore do not step out, but take up my former position.

And now I thank you all from the depths of my heart for your presence, and beg of you to retain for me a friendly remembrance.

EDITORIAL.

The recent publication by the United States Geological Survey of monographs on the Mesabi, Vermilion, and Menominee iron-bearing districts marks the approximate completion of a prolonged and systematic study of the great Lake Superior ore-bearing series and of the associated pre-Cambrian formations. There is yet to appear a supplementary and final volume on the geology of the Lake Superior region as a whole, which will bring together and correlate the general conclusions and maps of the district monographs. It is understood that this will be submitted for publication in 1905.

This notable series of reports was formally inaugurated in the late eighties by Dr. R. D. Irving, but was prefaced by his work on the Wisconsin survey in the seventies and early eighties. Dr. Irving's death in 1888, however, permitted him to see only the beginning of the monographic work in the Penokee-Gogebic district. The further execution of the plan fell to his associate, Dr. C. R. Van Hise, who, during the past sixteen years, has carried it forward to its present advanced stage. The first of the monographs to appear was the Penokee-Gogebic monograph, No. XIX, published in 1892. The field work for this was done jointly by Irving and Van Hise, but the writing of the monograph fell largely to the latter. In 1895 appeared the Marquette monograph, No. XXVIII, by Van Hise in collaboration with Professor W. S. Bayley. This was followed in 1899 by the appearance of the Crystal Falls monograph, No. XXXVI, by Professors J. Morgan Clements, H. L. Smyth, W. S. Bayley, and C. R. Van Hise; in 1903, by the Mesabi monograph, No. XLIII, by Dr. C. K. Leith; and finally, during the past winter, by the Vermilion monograph, No. XLV, by Clements and the Menominee monograph, No. XLVI, by Bayley, the latter having just come from the press. Monograph V, on the copper-bearing rocks of Lake Superior, by Irving, should also be mentioned, although it was published before (1883) the inauguration of the plan for the comprehensive investigation of the iron-bearing districts.

The total expenditure of the survey for this great series has been less than $150,000. Considering the magnitude of the iron-mining industry, and the intricacy and importance of the geological formations involved, the expenditure is very conservative. Larger sums than this, we are reliably informed, are spent by single mining companies in the Lake Superior region in the exploration of very limited areas; indeed, it is in a large measure due to the co-operation of such companies that this series of monographs has been prepared within the amount named.

The work of the survey is highly appreciated in the Lake Superior region, where a good geological and structural map has come to be regarded as an absolute prerequisite to intelligent underground exploration and mining development. The working maxim has been firmly established that before expensive underground exploration is attempted it is economy to spend whatever is necessary—which is usually a comparatively small amount—to ascertain all that can be learned at the surface. A proper geological map of the ore-bearing district saves many thousands of dollars in sub-surface exploration by limiting the areas which it is worth while so to explore. Professor Irving and his colleagues mapped in detail the iron-bearing formation of the Penokee-Gogebic district in the later seventies and early eighties, and up to the present time no ore-bearing areas have been found outside the narrow limits they laid down. While elsewhere, from time to time, exploration has enlarged the boundaries of the ore-bearing formations mapped by the earlier surveys, it is within limits to say that a vast amount of subsurface exploration which might otherwise have been done in barren areas has been localized in more promising fields by means of the geological maps.

This series of monographs constitutes a valuable contribution to the theory of ore deposition and to the intricate geology of the best known pre-Cambrian formations. Not only have they an intensive value to local mining men and to pre-Cambrian geologists, but they subserve a broader and scarcely a less important function in the dissemination, through the industrial and scientific world, of information relative to the sources, the extent, and the modes of origin of products which are the dominating factor in the most important metallic industry of America, if not of the world.

T. C. C.

REVIEWS.

Grundzüge der Geologie des unteren Amazonasgebietes (des Staates Pará in Brasilien). Von DR. FRIEDRICH KATZER. Leipzig, 1903. Pp. 302, royal 8vo; illustrations and one geologic map of the state of Pará.

THE author of this work has brought together and published in a volume of convenient size the chief matters of interest in regard to the geology and geography of the lower Amazonas, and especially of the state of Pará.

The volume opens with a geographic sketch of the region. This is followed by a brief history of the work done on the geology, and biographic notices of the men by whom the work has been done. It is an interesting fact that the bulk of our knowledge of the geology of Brazil dates from a visit made to that county in 1864 by Louis Agassiz. The work of Agassiz himself upon the geology was of no great importance, but his inspiration was far-reaching. C. F. Hartt, one of his assistants, returned to Brazil several times to continue work on the geology, and eventually died in that country. He took with him several assistants—Derby, Rathbun, H. H. Smith, and others—who have continued the work. After Hartt's death, in 1877, Derby remained in Brazil and has devoted his life entirely to the study of Brazilian geology. It was through his influence that descriptions were finally published of the rich Silurian, Devonian, Carboniferous, and Cretaceous faunas of Brazil.

Dr. Katzer himself was formerly geological assistant in the museum of Natural History at Pará, and in that capacity he traveled extensively through the Amazonas country. His interest in the geology of the region has led him to publish this volume even after he has left Brazil.

The biographic part is followed by descriptions of the different groups of rocks, and plates are given of the most important fossils from the fossiliferous horizons.

The volume is one of much value to those who wish to obtain a general knowledge of the geology of the Lower Amazonas region without having to seek it through a large number of papers published at widely different times and places.

J. C. BRANNER.

The Correlation of Geological Faunas: A Contribution to Devonian Paleontology. By HENRY SHALER WILLIAMS. [Bulletin of the United States Geological Survey, No. 210.] Washington, 1903.

IN the investigation of geologic problems concerned with correlation, two fundamentally different concepts must be kept continually in mind. The first of these has to do with rock strata, the media in which fossil organisms are preserved, and the classification of formations; the second has to do with fossil faunas or assemblages of organisms preserved in the rocks, and the classification of time periods. In the broad correlation of geologic formations the data furnished by the faunas are of prime importance, and too much cannot be said of the value of exhaustive researches upon fossil faunas as faunas.

The paper by Professor Williams on *The Correlation of Geological Faunas* is essentially a treatise upon the methods of investigation of fossil faunas, in which the Middle Devonian fauna of the New York province, characterized by *Tropidoleptus carinatus*, is especially used for illustration.

In the first two chapters of the work, "The Principles of Correlation" and the "Geological Expression of Faunal Migrations" are discussed in a manner applicable to any problem involving the study of fossil faunas. Chapter 3 is devoted to an application of the principles discussed in the preceding chapters, to an investigation of the history of the *Tropidoleptus carinatus* fauna. In treating of the "Shifting of Faunas" in chap. 4, illustrations are again drawn from the Devonian faunas of the New York province. The principles involved, and the effect of the shifting as expressed in the faunas themselves, are fully discussed. In considering the "equivalency" of formations in chap. 5, examples are taken from the correlation of the Devonian formations of New York and Ohio. The sixth and last chapter of the treatise is devoted to the "Bionic Value of Fossils." The application of the data furnished by species, genera, etc., of organisms, for the classification, not of rock formations, but of time periods, is discussed, and the chapter closes with the statement of a proposed "bionic time scale."

In this paper Professor Williams has assembled the more important results, both material and philosophical, which he has secured in the course of his long-continued investigations of the Middle and Upper Devonian faunas of New York. Many of these results have been previously published in various shorter papers, but here they are for the first time brought together in compact form. The paper is full of suggestions and should be studied by every student of fossil faunas.

STUART WELLER.

The Evolution of Earth Structure. New York: Longmans, Green & Co., 1903. By T. MELLARD READE.

THE author concludes that the continents and ocean basins arise from differences in the specific gravities of large sections of the earth. These specific gravities are not stable, but are subject to slow changes consequent upon changes of temperature. A rise of temperature and local increase of volume create protuberances which may be of continental extent. A fall of temperature and decrease of volume lead to depressions, which may culminate in the formation of deeps. "Thus it follows that these departures from the regular spheroidal forms are not original and permanent; nor are they features which have been growing from the dawn of geological history, such as would be likely to occur from a differential radial shrinkage of the earth." Evidence of thermal fluctuations is given by the varying composition, specific gravity, and temperature of lavas from time to time emitted from vents. "The extrusion of lavas is largely due to increase of temperature and consequent increase of volume. Relief by extrusion causes a reduction of temperature, and shrinkage takes place in the supplying reservoir. This results in a subsequent period of quiescence, which lasts until the molten matter of the reservoir again becomes hot enough to compel extrusion."

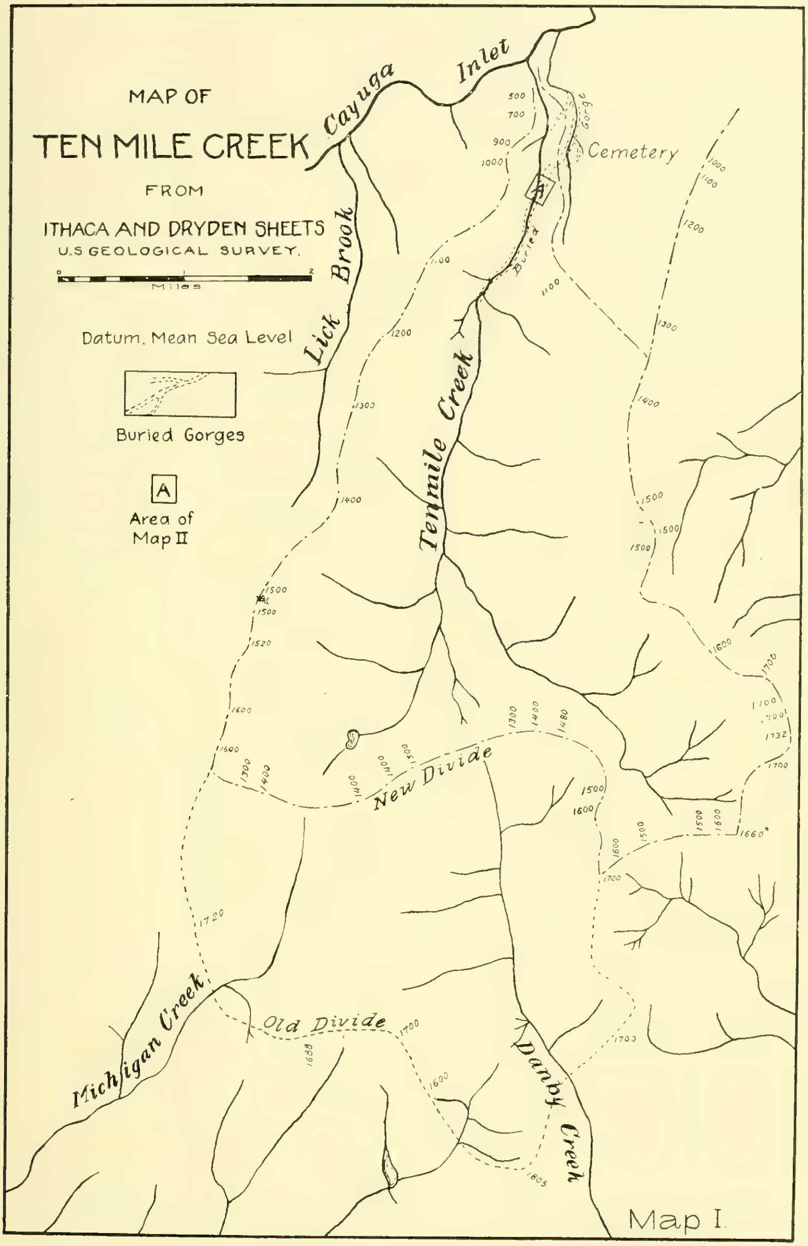
The author holds tenaciously to the theory which he advanced in a former work,[1] that mountain ranges are caused by sedimentation and a subsequent heating of the sediments. Numerous cuts of models illustrating earth movements are introduced, with a full discussion of the experiments.

W. H. E.

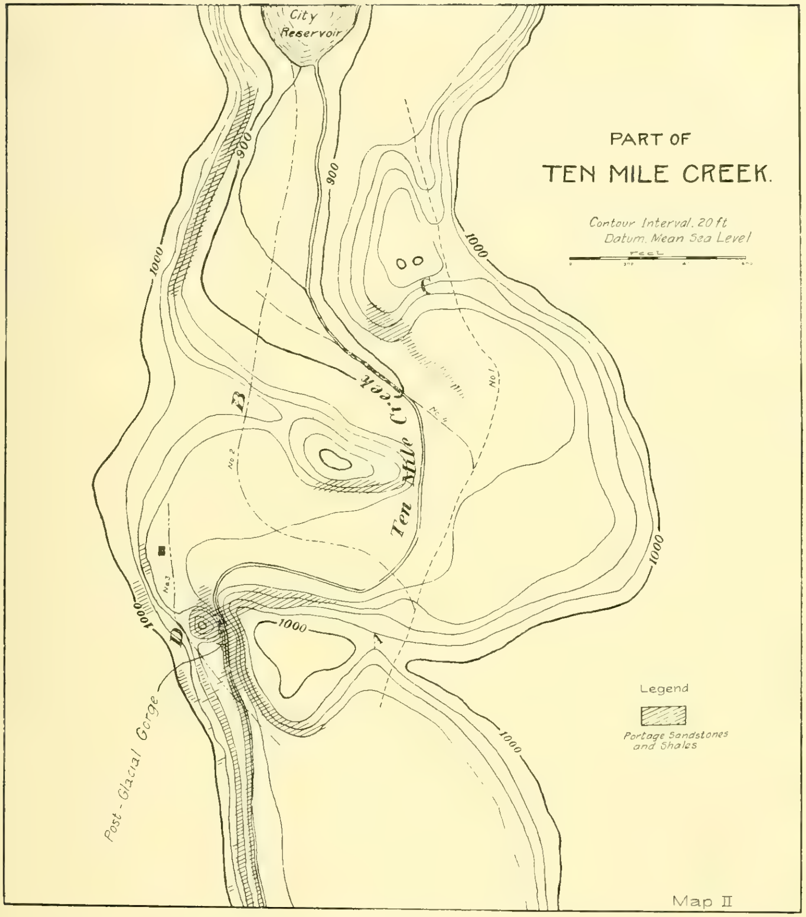
NOTE OF EXPLANATION.

BY an oversight, Maps I and II (Ten Mile Creek) of the paper of Mr. George C. Matson entitled "A Contribution to the Study of the Interglacial Gorge Problem," which appeared in the February-March number of the JOURNAL, were omitted. They are inclosed with this number, and may be inserted between pages 140 and 141 of the February-March number.

[1] *The Origin of Mountain Ranges.*



(This map should be inserted in Vol. XII, No. 2, February-March, 1904, of the JOURNAL OF GEOLOGY, to face page 140.)



(This map should be inserted in Vol. XII, No. 2, February-March, 1904, of the JOURNAL OF GEOLOGY, to face page 142.)

THE

JOURNAL OF GEOLOGY

MAY–JUNE, 1904

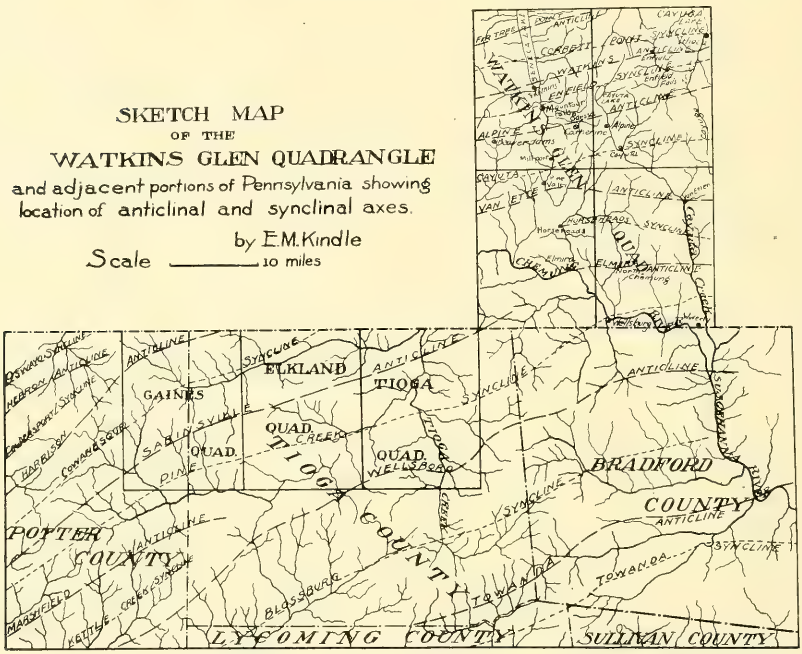
A SERIES OF GENTLE FOLDS ON THE BORDER OF THE APPALACHIAN SYSTEM.[1]

THE conclusions of this paper have been reached in the study of the Watkins Glen quadrangle, New York. This quadrangle comprises the four fifteen-minute quadrangles known as the Watkins, Ithaca, Elmira, and Waverly quadrangles. Extending from the Pennsylvania state line to the Seneca and Cayuga Lake valleys, it includes the southern portion of each. This area lies immediately north of the region of the Appalachian folds. The surface rocks of the quadrangle are the shales and sandstones of the Chemung, Portage, and Genesee formations. The rock strata over much of the area vary so little from the horizontal position that the dip can usually be recognized only by the very careful use of the clinometer or the level. Dips high enough to be conspicuous, and ranging from 8 to 55°, have been noted occasionally in various parts of the quadrangle, but these high dips have in nearly all cases been found to be associated with small local anticlines or faults, extending frequently only a few rods and possessing only local interest. With these higher dips the present paper is not concerned; but the interpretation of the more obscure dips ranging usually from 1 to 3 or 4° will be attempted.

A careful study of the low dips characterizing the rocks over the major part of the quadrangle has shown them to have an important structural significance. They have been found to represent a series of low, approximately parallel, anticlinal folds, having the same general direction as the great mountain folds immediately south of them in Bradford county, Pennsylvania.

[1] Published by permission of the director of the U. S. Geological Survey.

Very gentle dips ranging from $\frac{1}{2}$ to 5°, but rising in a few instances to 10° or more, characterize these folds. Although very low, they belong to anticlinal folds, which are very persistent. Some of them have been traced entirely across the quadrangle. Five of these folds, separated by a corresponding number of synclines, have been recognized. Beginning at the north, the folds will be designated by the



following names: the Fir Tree Point anticline, the Watkins anticline, the Alpine anticline, the Van Etten anticline, and the Elmira anticline. The position of these minor folds with reference to the nearest Allegheny folds is shown by the accompanying sketch map.[1]

Fir Tree Point anticline.—This fold has a width along Lake Seneca of five and one-half miles. The axis crosses the lake at Fir Tree Point, two and a half miles south of the northern edge of the quadrangle, bearing a little north of east. Nearly continuous

[1] The location of the Pennsylvania folds shown by the map is based upon maps published in the *Pennsylvania State Geological Reports* and in *Folio No. 93*, U. S. Geological Survey.

exposures of the rock in the lake shore cliffs on each side of the anticlinal axis, as far as the synclinal axes limiting the arch make it possible to measure accurately the total height of the arch by noting the thickness of the successive beds as they rise above the lake level. Measured in this way, the crest of the anticline is found to rise about 115 feet above the troughs of the synclines on each side. This anticline therefore brings to view 115 feet of strata which are below lake-level at the northern edge of the quadrangle. This includes about 75 feet of typical Portage sandstones and shales, and some forty feet of black and dark gray shales which represent the transition between the Portage and the Genesee, corresponding to the Middlesex shales of Clarke and Luther.

The north dips terminate at the synclinal axis crossing the lake on the east side at the edge of the quadrangle north of Peach Orchard and just north of Glenora on the west side. The axis of the Corbett's Point syncline to the south of this fold crosses the lake just north of Corbett's and Cottage Points, three miles south of the anticlinal axis. The amount of the north and south declinations of this fold along Seneca Lake are practically the same, but its axis is a half-mile nearer to the synclinal axis on the north than it is to the synclinal axis on the south, so that the inclination of the north limb is somewhat greater than that of the south limb.

It is very probable that the anticline crossing Lake Cayuga in the vicinity of Shurger Point, which has a maximum elevation of 235 feet on the east side and 160 feet on the west side,[1] is the northeastern continuation of the Fir Tree Point anticline, but the continuity of the two has not been verified by a study of the dips in intervening territory. Along Lake Cayuga, south of Shurger's Point south dips continue until the synclinal axis at Ithaca is reached, the rate of dip being about 110 feet per mile.

Watkin's anticline.—Six miles south of Fir Tree Point a second, but much lower, fold crosses the south end of Lake Seneca. Its axis crosses the lake just north of Watkins, six miles south of Fir Tree Point. Continuing eastward by northeast, it crosses the Cayuga Inlet valley in the southern edge of Ithaca. The maximum height of the fold above the syncline on the north is about 35 feet. A band

[1] *American Journal of Science*, Vol. XXVI (1883), p. 304.

of heavy-bedded sandstone outcropping at the foot of the cliffs just below the entrance to Watkins Glen affords a convenient datum plane from which to determine the height of the Watkins fold. This is the only band of sandstone exceeding 10 or 12 inches in thickness in this part of the section, and it is easily followed from its outcrop north of Salt Point, where its base is only a few inches above lake level to Watkins, where it reaches its maximum elevation of 30 feet above the lake in a ravine just north of the village.

This sandstone band dips below lake-level about 500 yards north of Salt Point. From the point where it disappears to the axis of the syncline the north dip does not exceed 10 feet, so that the total rise of the fold above the Corbett Point syncline is probably between 35 and 40 feet. On the east side of the lake the maximum elevation of the fold, which is about 10 to 12 feet less than on the west side, is attained at the quarry just north of Excelsior Glen. From this point, where the band of massive sandstone mentioned above is 20 feet above lake-level, the dip is very gentle to the north, the sandstone band reaching lake-level at the north side of "Painted Rocks," about one mile north of Excelsior Glen. South of Watkins the Watkins Glen sandstone is seen at the base of the quarry half a mile below town. A short distance south of this point it dips below the level of the marsh.

At Ithaca the very gentle north dips of this fold are seen along the west side of the Inlet valley from the south edge of town nearly to the lake. The much heavier south dips appear in South Hill. The south dips of this fold both at Ithaca and Watkins greatly exceed the north dips. The synclinal axis between this fold and the next on the south passes a little north of Montour Falls and Lake Cayuta, through the village of Enfield and out of the quadrangle east of the upper dam in Buttermilk Creek.

Alpine anticline.—The strongest fold in the quadrangle is the next one south of the Watkins fold and running parallel with it. The axis of this fold enters the quadrangle nearly west of Beaverdams. Passing a little north of Beaverdams and south of Moreland, it crosses Catherine Creek valley about five miles south of the head of Seneca Lake, and Cayuta Creek one mile north of Alpine. The axis crosses Cantor Creek one and a half miles north of Pony Hollow; passing

between Newfield and Stratton, it continues northeasterly to the edge of the quadrangle. Continuing this axis into the Dryden quadrangle, in the same direction which it follows in the Ithaca quadrangle, it joins the anticline which in the vicinity of Brookton is represented by southerly dips of 5 to 6°.

The northerly dips of the Alpine anticline usually vary between 1 and 2°. North dips as high as 3° have, however, been observed in the quarry in Odessa, and along Cayuta Creek one mile south of Cayuta Lake. The south dips are much stronger than the north dips, and vary from 3 to 10°. Northeast of Chambers south and southeasterly dips of from 3 to 8° are seen. In the ravine east of Alpine half a mile the dips range from 8 to 10° in a southeasterly direction. Just west of West Danby the south dips vary from 3 to 6°. The average south dip for this fold is probably $3\frac{1}{2}$ or 4°.

It will be noted that the total south dip in this quadrangle of the rocks to the north of the axis of the Alpine anticline is very small. The much greater inclination of the beds to the south of this axis over those to the north of it makes the effective south dip along the southern edge of this fold much greater than elsewhere in the quadrangle, and explains the abrupt appearance of the Chemung in all of the hills on the south flank of this fold.

The synclinal axis to the south of this fold enters the region about a mile south of the northwest corner of the Elmira quadrangle. Passing northeasterly through Millport, it crosses Cayuta Creek just south of Cayuta and leaves the quadrangle about one mile north of the Chemung-Tompkins county line.

Van Etten anticline.—The axis of this fold crosses Cayuta Creek at Van Etten. Bearing a little to the north of west, it crosses Catherine Creek about a half-mile south of Pine Valley, thence, trending a little south of west, it passes just north of Catherine, and probably leaves the quadrangle to the west of Quackenbush Hill. The north and south dips of this fold may be seen along nearly all of the streams which it crosses. The dips of the north limb of the fold are particularly well displayed in the outcrops along Dry Run, Langford Creek, and Cayuta Creek. The dips of the south limb of the fold may be seen along Dean Creek, Cayuta Creek, Baker Creek, and a number of other small streams to the south of the axis, varying usually from 2 to 3°.

The synclinal axis south of the Van Etten fold crosses Cayuta Creek apparently about two and three-quarters miles north of Reniff. Its position has been recognized just east of Horseheads, but west of this point the complexity of the dips renders the determination of its course uncertain.

The Elmira anticline.—The axis of the southernmost anticlinal fold in the quadrangle runs eastward from about the abrupt southerly bend of the Chemung River east of Elmira; passing south of North Chemung and just north of Chemung Centre, it crosses Cayuta Creek just north of Lockwood. At Lockwood the north limb of the anticlinal has flattened until the dip cannot be detected by the clinometer or hand-level, but there is probably a very small north dip for two and one-half or three miles up the valley to the point where the south dips of the Van Etten fold cease. In the western half of the Waverly quadrangle the north dips are pronounced along Baldwin Creek northeast of North Chemung and its tributaries to the west of North Chemung. The north dip at the quarries east and north of Elmira, which averages about 2°, may be observed nearly to Horseheads. The south dips of this fold along the east side of the Chemung River range from 3 to 5° south or southeast. The south dips east of this may be seen along nearly every south-flowing stream to the eastern edge of the Waverly quadrangle. The course of the fold west of Elmira is not entirely clear. Sherwood recognized the Elmira anticline as a continuation of a Pennsylvania fold and states that "it crosses the Chemung River a little below Elmira."[1] Sherwood states that he "has seen no dips beyond Elmira and Horseheads."[2] Heavy southwest dips for two miles along the river west of the city and also north of the summit of Hawley Hill indicate the probability, as suggested by Mr. M. L. Fuller, that the axis bends to the north, west of Elmira, passing between Hawley and Hawes Hills. Thence, bending southward, it probably joins the Sabinsville anticline near the southwestern corner of the quadrangle.

The syncline to the south of the Elmira anticline is well defined in the southeastern part of the Waverly quadrangle. The axis crosses Cayuta Creek about three miles north of Waverly. Passing westward between Shoemaker Mountain and Narrow Hill, it crosses

[1] *Report G*, Pennsylvania Geological Survey, p. 95. [2] *Ibid.*, p. 96.

the Chemung River to the north of Wellsburg. Apparently it bears sharply to the southwest near this point and joins the Pine Creek syncline of Pennsylvania. While the connection between the Pine Creek and Narrow Hill synclines has not been clearly established, the rather abrupt eastward bend of the former, which follows, if they are continuous, is in harmony with the sudden change in the trend of the Wellsburg anticline and the Blossburg syncline on the south from northeast to east.

It appears certain that the comparatively insignificant structural features which have been described are of the same age and origin as the great open folds of the northern Alleghenies. In the quadrangle cornering with the Watkins Glen quadrangle on the southwest are folds whose arches, if restored, would rise 2,500 feet above their troughs.[1] Less than twenty miles to the south of the Watkins Glen quadrangle another great fold shows a crest of similar or greater elevation. From theoretical considerations it would appear improbable that the effects of the epirogenic forces which have developed structures of such magnitude should terminate abruptly at the northern edge of the highly folded belt. Instead of abrupt change from highly folded to monoclinal or nearly horizontal structure, we find the mountain flexures subsiding gradually into the low, gentle swells which have been described. This may be illustrated by a comparison of the maximum dips exhibited by the anticlinal folds encountered between South Mountain in Bradford county, Pennsylvania, and the southern end of Lake Seneca. Eighteen miles south of the Watkins Glen quadrangle runs the axis of the Towanda anticline between two synclinal mountain ridges—Mount Pisgah and South Mountain. Dips of 70° or more have been observed on the south side of this anticline, but the average dip for the belt of maximum inclination is approximately 40°. The dips of the north limb of this fold are very much lower than the south dips. The writer, although familiar with the region, has not observed any dips which will exceed 20°, and the dips in the zone of maximum inclination will probably not average more than 15°. It is noteworthy that the great excess of the south dip over the north dip of this fold is a characteristic common to nearly all folds of the Watkins Glen quadrangle.

[1] *Folio No. 93*, U. S. Geological Survey, p. 5.

The next anticlinal axis north of the Towanda anticline approaches to within about six miles of the southern edge of the Watkins Glen quadrangle. This anticline, which is known as the Wellsburg anticline, does not differ greatly, as developed in Bradford county, from the Alpine anticline of the Watkins Glen quadrangle in the magnitude of the dips, which seldom exceed 5° in Bradford county. The latter has, however, less than half the width of the Wellsburg anticline, which accounts for the failure of the Alpine anticline to develop synclinal mountain ridges, such as those associated with the Wellsburg fold. In the Elmira fold, which is the next fold north of the Wellsburg syncline, the maximum dips have dropped to 2° for the north limb and about 3 or 4° for the south limb. The Watkins, fold, which is about fifteen miles north of the Elmira fold, may be cited as showing the smallest dips of any fold in the quadrangle, the maximum amounting to 1° or less.

It follows as a result of the anticlinal structure which has been described that the total southerly declination of the beds of the quadrangle, amounting to several hundred feet, is not the result of a regular or approximately uniform rate of dip to the south per mile, as has been generally assumed.[1] On the contrary, the rocks rise toward the south on the north side of each of the axes described. The dip of the south limb of the fold is, however, as stated above, usually greater than the north dip. In the case of the Alpine anticline the south dip is very much greater than the north dip, the result being that the total of the south dips in the quadrangle considerably exceeds the north dips, and that any given horizon at the south side of the quadrangle is several hundred feet lower than at the north side.

Between the south end of Lake Cayuga and Newfield the north and south dips about balance each other, the beds of a given horizon being at nearly the same level at these two points. The same is

[1] Since completing the field work on which this paper is based, the writer's attention has been called to a paper by Professor H. S. Williams (*Proceedings of the American Association for the Advancement of Science*, Vol. XXXI (1882), p. 412), which gives a brief description of folds corresponding to the eastern portion of some of those herein described. Hall observed the north dips between Elmira and Horseheads in 1839, and states that the rocks rise "southward from Horseheads to the Chemung River." (*Third Annual Report, Fourth Federal District*, p. 323.)

true of the dips of the beds in the Seneca Lake valley—similar horizons lying as high or higher at the axis of the anticlinal fold two miles south of Montour Falls as at Cottage Point eight miles north. On crossing the axis of the Alpine anticline, however, a south dip ranging from 3 to 8° brings the beds very rapidly toward sea-level.

The various maps of the New York State Survey, which cover portions or the whole of this region, have evidently been constructed on the supposition of an approximately uniform southerly dip in the region about the southern ends of the Seneca and Cayuga Lake basins. As a consequence, the Chemung-Portage parting, as shown on these maps, involves an inaccuracy of several miles in many places. In the "Finger Lakes Sheet," and the revised state map published in 1901, the northern limit of the Chemung between the Seneca and Cayuga basins is drawn about ten miles south of its actual northern limit, while the Portage has been found by the writer above drainage several miles south of the southern limit shown by the map.

The conclusions stated above have, as shown, been reached through a study of the stratigraphy, but supplementary paleontologic work has been found to confirm them throughout. The writer has found typical Chemung fossils at the northern edge of the Watkins quadrangle, about ten miles north of the northern limit of the Chemung, as given by the New York state map for that meridian. Due east of Ithaca, *Spirifer disjunctus* has been found in the higher beds, which have heretofore been supposed to belong to a Portage terrane and which lie about seven miles north of the Portage-Chemung boundary for that region, according to the New York state map.

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THE LARAMIE AND FORT UNION BEDS IN NORTH DAKOTA.

WHILE considering economic problems in North Dakota and eastern Montana, abundant opportunity was given to examine the beds that in geological literature have long been known as the Fort Union, and to compare them with beds that have been assigned without question to the Laramie. From this study certain definite impressions were gained in regard to the relationship existing between the Fort Union beds and the Laramie. In stating these impressions, no effort will be made to contribute to the already abundant literature bearing on the larger question of the position of the Laramie as a whole.

The field work covered six months in the years 1902 and 1903, the area studied including the entire western half of North Dakota and eastern Montana along the Yellowstone. The unusual exposures along the Missouri throughout the three hundred miles of its course in North Dakota were examined, the trip down the river being made by boat. From the western boundary of North Dakota the river passes from beds that have been regarded as typical Fort Union, to an area that has been assigned without reserve to the Laramie. The tributaries of the Missouri from the west and the bad lands also give abundant opportunity for stratigraphic study.

Though eager to discover vertebrate remains, none were found, except great numbers of buffalo bones in the lower river terraces. Molluscan and plant fossils, however, were collected at a number of points. The molluscs were identified by Mr. T. W. Stanton, and the plants by Mr. F. H. Knowlton, of the U. S. Geological Survey, and those that seem to be suggestive in considering the relation of the Fort Union to the Laramie will be noted.

The area supposed to be occupied by the Fort Union beds has never been definitely outlined. Lesquereaux[1] states that they occupy

the whole country about Fort Union, extending north into the British possessions to unknown distances; also southward to Fort Clarke; seen under the White River group, on North Platte River, above Fort Laramie; also on west side of Wind River Mountains.

[1] *United States Geological Survey*, Vol. VII, p. 24.

The older reports of the United States Geological Survey locate Fort Union variously in North Dakota and Montana. The place has long since disappeared from the map, and the site is now represented by Fort Buford, which is located on the Missouri River only three miles from the mouth of the Yellowstone. The confusion in regard to states arose from the fact that the old Fort Union, while located in North Dakota, was only three miles from the Montana line.

The following sections, taken at Glass Bluffs, on the south bank of the Missouri and four miles below Fort Buford, illustrates the beds commonly designated as Fort Union.:

			Feet	Inches
	13	glacial drift	25	
	12	gravel, well rounded, fresh	4	
Fort Union	11	clay, sandy	90	
Fort Union	10	sandstone	2	
Fort Union	9	clay, blue, sandy	48	
Fort Union	8	clay	2	
Fort Union	7	lignite, impure		3
Fort Union	6	clay	4	
Fort Union	5	lignite, fair quality	5	
Fort Union	4	clay, hard, yellow	4	
Fort Union	3	clay, fat	6	
Fort Union	2	lignite, good quality, with 3 in. clay in middle	3	6
Fort Union	1	yellow clay, growing sandy toward the top	35	
			228	9

Instead of being in any way remarkable, this section would serve to illustrate the prevailing characteristics of the Laramie as well as it does the Fort Union. In North Dakota, at least, there is nothing peculiar in the beds, their composition or position, that will differentiate the Fort Union from the Laramie. If a number of descriptions of Laramie sections taken from the Little Missouri country south of Medora, or north of Bismarck were written with sections from about old Fort Union, it is practically certain that the regions from which they came could not be distinguished. A large number of sections like the one just quoted, but taken from regions that have always been regarded as Laramie, have been published elsewhere.[1] In a single area, in the southern part of the state near the mouth of the Cannon Ball River and extending back from the Missouri for sixty miles, the Laramie differs from the so-called Fort Union beds

[1] *Second Biennial Report of the North Dakota Geological Survey*, 1901–2.

about Fort Buford. As exposed along the Cannon Ball River, the Laramie is made up for the most part of sand and sandstone, while lignite is present only in thin beds, and clay is second to sand in abundance. Here, however, *Corbicula nebraskensis* M. & H. is found in abundance, which was originally reported from the Fort Union of the Northwest.

Shells were found in abundance at a number of points, the following forms being frequently noted:

Viviparus trochiformis M. & H.

Campeloma multilineata M. & H.

Unio priscus M. & H.

These were found alike about old Fort Union and in the Laramie, and at various horizons.

At a number of points leaf-prints were found. Ten miles north of Minot and one hundred and twenty miles east of old Fort Union, a clay bed between two lignite seams occurs, filled with the following forms:

Sequoia angustifolia Lesq.

Sequoia Langsdorfii (Brongniart) Heer.

Sequoia brevifolia Lesq.

At least one of these forms was found at Mannhaven, eighty miles north of Mandan. Though the Fort Union has never been definitely outlined, no one seems to have extended it to these points. In these two localities the leaf-prints had a nearly common elevation of 1,600 feet, while the lowest beds exposed on the Missouri River at old Fort Union are 1,800 feet above the sea.

Near Coal Harbor, which is eighty miles north of Bismarck, at an elevation of 100 feet above the Missouri River, and both outside of and below the Fort Union beds, as they are commonly understood, a limestone layer about two feet thick occurs, which abounds in leaf prints. From this limestone the following were taken:

Credneria? daturiaefolia.

Phyllites cupanioides Newb.

Celastrus (probably).

In his note returning the fossils, Mr. R. S. Bassler, of the U. S. National Museum, to whom the specimens were sent, says: "Mr. Knowlton, of the United States Geological Survey, has kindly identified them, and says that their age appears to be Fort Union."

Phyllites cupanioides is noted in Newberry's[1] list as occurring only in the Fort Union.

As a result of two summers of field work in North Dakota, the very definite impression remains that, at least in that state, there is great difficulty in retaining the term "Fort Union beds," since they never have been, and apparently cannot be, set off from the Laramie either in vertical or horizontal extent. The conclusion of White[2] seems to be wholly justified:

> In eastern Montana and western North Dakota the Laramie strata are similarly connected, by specific identity of molluscan remains and by apparent continuity of sedimentation, with those which there are reported to bear a purely Tertiary flora, and which have generally been designated the Fort Union group.

From the standpoint of paleobotany, Clark[3] indicates that the same conclusion may be reached. He quotes Professor Newberry,[4] who held that the two formations should be referred to different horizons, the Laramie to the Cretaceous, and the Fort Union to the Tertiary. These quotations he follows immediately with others from Professor Ward, who, discussing the statements of Dr. Newberry, says:

> that, although the difference in flora exists, "yet the Laramie and Fort Union must go together," and offers in explanation "that possibly the latitude, taken in connection with a different topography, such as may have existed in the two regions, might account for the great difference in the floras." Professor Ward further gives a list of eight identical species from the Laramie and Fort Union groups.

Knowlton[5] also holds that there can be scarcely any doubt that the flora of the Upper Laramie, of the Atanekerdluk series in Greenland, and of the Spitzbergen and Alaskan territories is identical with the Fort Union flora of the Missouri region.

In mapping North Dakota, therefore, there seems to be no satisfactory reason for noting Fort Union beds as distinguished from the Laramie. Indeed, to make such a distinction seems practically impossible.

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April 30, 1904.

1 Monograph XXXV, *The Later Extinct Floras of North America*, p. 150.

2 *Bulletin No. 82*, U. S. Geological Survey, p. 149.

3 *Ibid.*, *Bulletin No. 83*, p. 135.

4 *Geological Society of America, Bulletin*, Vol. I (1890), pp. 524–27.

5 *Proceedings of the National Museum*, Vol. XXVII (1894), p. 240.

ORBICULAR GABBRO-DIORITE FROM DAVIE COUNTY, NORTH CAROLINA.[1]

GENERAL STATEMENT.

SPHEROIDAL or orbicular structures have been observed in granites and diorites among plutonic rocks from many parts of the world, and especially celebrated are some of these occurrences in North America and Europe. The best-known of the European localities are Fonni[2] in Sardinia, Wirvik[3] in Finland, Slätmossa[4] in Sweden, Riesengebirge[5] in Silesia, Mallaghderg[6] in County Donegal, Ireland, and Corsica. In America the structure seems to have been less often observed than in Europe, though a number of occurrences have been described, mostly among granites, from widely separated localities. These have been made known through the publications of Edward Hitchcock,[7] Hawes,[8] Chroustschoff,[9] von Rath,[10] Zirkel,[11] Kemp,[12] F. D. Adams,[13] and Lawson,[14] which include the following

[1] Published by permission of the state geologist of North Carolina.

[2] G. VON RATH, *Sitzungsberichte der Niederrheinischen Gesellschaft*, Bonn, June, 1885, p. 201; F. FOUQUE, *Bulletins de la Société mineralogique de France*, Vol. X (1887), p. 57.

[3] B. FROSTERUS, *Tschermaks Mineralogische und petrographische Mittheilungen*, Vol. XIII (1898), p. 177; Bull. Com. Geol. Finland, 1896, No. 4.

[4] W. C. BRÖGGER, OCH H. BÄCKSTRÖM, *Geologiska Föreningen i Stockholm, Förhandlinger*, Vol. IX (1887), p. 351; H. BÄCKSTRÖM, *ibid.*, Vol. XVI (1894), p. 107; N. D. HOLST, OCH F. EICHSTADT, *ibid.*, Vol. VII, p. 134.

[5] F. H. HATCH, *Quarterly Journal of the Geological Society*, Vol. XLIV (1888), p. 548.

[6] G. ROSE, *Poggendorff's Annalen*, Vol. LXI, p. 624.

[7] *Geology of Vermont*, Vol. II (1861), p. 564.

[8] *Geology of New Hampshire*, Vol. III (1878), Part 4, p. 203.

[9] *Bulletins de la Société mineralogique de France*, Vol. VIII (1885), p. 137.

[10] *Sitzungsberichte der Niederrheinischen Geschellschaft für Natur- und Heilkunde*, December, 1, 1884.

[11] *Fortieth Parallel Survey*, Vol. VI (1878), p. 54.

[12] *Transactions of the New York Academy of Sciences*, Vol. XIII (1903), pp. 140–43 *Science*, N. S., Vol. XVIII (1903), p. 503.

[13] *Bulletin of the Geological Society of America*, Vol. IX (1898), p. 163.

[14] A. C. LAWSON, "The Orbicular Gabbro Diorite at Dehesa, San Diego county, California," *The University of California Publications*, Bulletin, Department of

principal localities: the "prune" or "pudding" granite of Craftsbury, Vermont; the orbicular diorite at Rattlesnake Bar, El Dorado county, California; the granite from Clark's Peak, Medicine Bow Range, Colorado; orbicular granite from Quonochontogue Beach, Rhode Island; a spheroidal granite from near Charlevoix, Michigan, in the northwest portion of the Lower Peninsula; a nodular granite from from Pine Lake, Ontario; and the orbieular gabbro at Dehesa, San Diego county, California.

The nodules of spheroidal rocks are considered similar in some respects to the dark segregations, or "schlieren," so frequently observed and described in granites. Like the spheroids, the dark segregations are usually more basic in composition than the general magma out of which they have segregated. A noteworthy exception to this, however, is the nodular granite from Pine Lake, Ontario, described by Adams,[1] the nodules of which are very appreciably more acid than the granite matrix, although the analysis[2] of the matrix indicates a very acid granite. The schlieren of granites in general are often of rounded outline, and at times show a sharp line of demarkation from the inclosing matrix, but, as a rule, they display no tendency to separate from the granite when broken. In many cases the segregations (schlieren) and spheroids are quite similar in mineral composition, but the dark segregations do not manifest the concentric and radiating structures characteristic of the spheroidal nodules.

Last summer (1903), while engaged in field study of the granites of North Carolina for the State Survey, the writer had occasion to examine very carefully in the field an orbicular gabbro-diorite in Davie county,[3] and later to study, microscopically, thin sections cut

Geology, Vol. III (1904), pp. 383–96; abstract, *Science*, N. S., Vol. XV (1902), p. 415.

Some of the references given above on the European localities have not been accessible to me. Those not accessible have been quoted from PROFESSOR KEMP'S paper in the *Transactions of the New York Academy of Sciences*, cited above; and from SIR A. GEIKIE'S *Text Book of Geology*, 1903, 4th ed., Vol. I, pp. 206, 224.

[1] "Nodular Granite from Pine Lake, Ontario," *Bulletin of the Geological Society of America*, Vol. IX (1898), pp. 163–72.

[2] *Ibid.*, p. 169.

[3] Knowledge of the existence of this rock dates back many years, but, so far as I am aware, a full description of it has not been published. Very brief mention of it

from hand specimens of the rock collected. Certain peculiarities of occurrence, structure, and composition of this rock not previously noted, so far as I am aware, among deep-seated rocks developing the spheroidal structure, seemed worthy of careful study. Further interest attaches to this rock for the reason that, as yet, it forms the only example of orbicular structure among deep-seated rocks found in the southern Appalachian region, and also because it adds a rock type which, in some respects, is a new one developing nodular or spheroidal structure.

GENERAL DESCRIPTION OF THE OCCURRENCE.

Exposures of the orbicular rock occur in the eastern part of Davie county on the Hairston farm, about ten miles west of Lexington and within one and a half miles of the Yadkin River. A peak or knoll of moderate size, rising about thirty feet in elevation above the surrounding plain and composed of huge bowlders, affords the only exposure of the fresh rock. Several of the larger bowlders have been split and partially worked off at different times, chiefly for use about the Hairston residence and to a less extent for museum specimens.

Traced southwestward from the knoll is found complete evidence of the extension in that direction of the orbicular gabbro-diorite, in the residual decay and in occasional partially decayed fragments of the rock scattered over the surface. The decay is of a pronounced dark, nearly black color, with a distinct greenish tint imparted by the ferromagnesian constituent of the fresh rock. Oxidation of the iron in the iron-bearing minerals of the decay is not appreciably apparent at any point. As nearly as could be determined, the zone of residual decay derived from the gabbro-diorite averages several hundred feet in width and extends approximately one-half to three-quarters of a mile southwest from the koll. Fairly sharp contacts between the decay of the orbicular diorite and that of an inclosing gray porphyritic biotite granite were noted in a number of places, which strongly suggest that the orbicular rock forms a dike having an approximate northeast-southwest strike, penetrating the porphyritic biotite granite.

is made in the following publications: J. V. Lewis, "Notes on Building and Ornamental Stone," *First Biennial Report of the State Geologist*, 1891-92, North Carolina Geological Survey, 1893, p. 91; George P. Merrill, *Stones for Building and Decoration* (New York, 1897), 2d ed., p. 259.

The field relations between, and the mineral composition of, the diorite and granite suggest different periods of intrusion of the two rocks, in the Carolina locality. Close by and approximately paralleling the general direction in strike (northeast-southwest) of the orbicular gabbro-diorite are some half-dozen dikes of massive unaltered

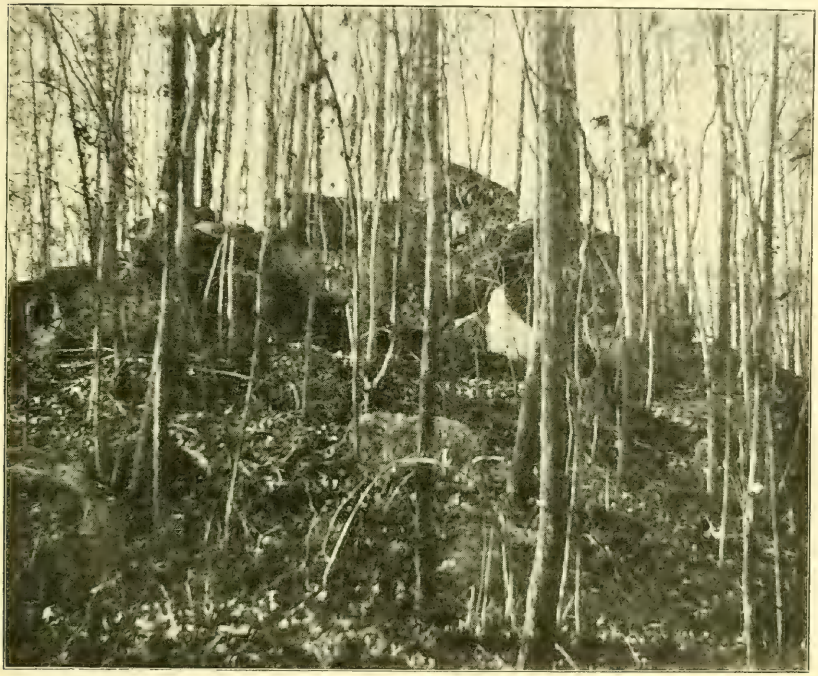

FIG. 1.

normal diabase which penetrate the porphyritic granite. While conclusive evidence is lacking, it is not improbable that the orbicular diorite and the neighboring dikes of diabase are of the same age. Southwestward a short distance from the knoll of exposed masses of the typical orbicular structure, the rock loses its characteristic nodular or spheroidal structure and assumes a pronounced granitic texture of rather coarse grain, but composed of the same minerals and of the same general dark color.

The color of the orbicular rock is dark, with a greenish tint imparted by the dark green ferromagnesian minerals. As indicated

in Fig. 2, the spheroidal growths compose by far the bulk of the rock. Variation of the nodules is from nearly perfect spheres to ellipsoidal in shape, and in size they range from a fraction of an inch to several inches across. They can readily be broken out of the rock in complete form, almost or entirely free from the inclosing matrix. Compression due to flow movements in the rock while still plastic is but slightly indicated in the shapes of the nodules.

The nodules are uniformly greenish black in color, composed, as a rule, almost or entirely of dark ferromagnesian minerals, which show a radial arrangement about a common center. They are usually crowded close together, touching each other in many cases, with the interspaces largely filled with clear white cleavable and lustrous feldspar, a very little quartz, and penetrating laths of hornblende. Relatively large and small perfect crystals of reddish-brown titanite are very generally distributed through the rock, common to both nodules and matrix. In some instances feldspar and quartz, rarely pyrite, in small grains, have been observed, each in different spheroids, to form a nucleus about which the somewhat fibrous ferromagnesian minerals have arranged themselves in a radial structure. Both the feldspar and the quartz may occur together, forming the nucleus of a single nodule. Of the nucleal minerals feldspar is perhaps the most common. In a majority of the spheroids, however, the nucleus or core of feldspar and quartz practically fails, when the nodules become spheres of ferromagnesian minerals.

Search through the literature develops, from descriptions of orbicular structure in deep-seated rocks, several important differences in structure and composition of the spheroids in the Carolina rock from those usually observed in similar rocks from other localities. The chief differences to be noted are: (1) In the Carolina rock the spheroids are marked by the almost entire absence of concentric structure, which ordinarily characterizes the nodules of deep-seated orbicular rocks described from other localities. Only the barest semblance of such structure is noted in the Carolina rock, and it entirely fails in most of the spheroids. (2) The spheroids of orbicular rocks hitherto described are composed of several minerals, usually the principal constituents of the groundmass, though additional ones

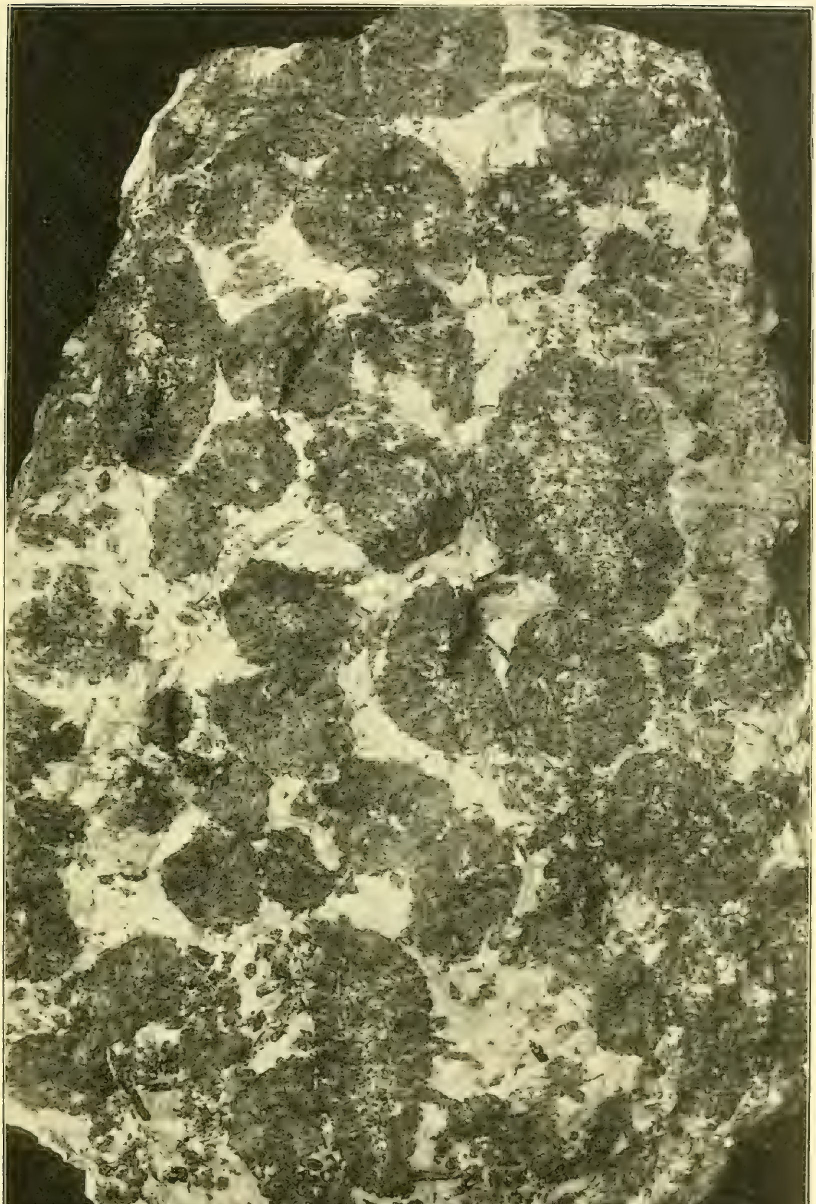

Fig. 2.

not present in the groundmass may occur, in some cases, in the nodules. As would be expected, difference in color for different parts of the spheroid would naturally follow from such a structural arrangement of the differently colored minerals, such as feldspar and quartz with one or more of the dark silicates. In the Carolina rock the spheroids are very generally composed of the dark silicates, in many of which the light-colored minerals, quartz and feldspar, entirely fail, hence they are very basic in composition and are of the same uniformly dark greenish color throughout. The feldspar filling the interspaces is often penetrated by large laths of the black lustrous hornblende, which may either have contact with, or extend from, the spheroid, or be entirely separated therefrom and inclosed wholly by the feldspar. (See Fig. 2.)

MICROSCOPICAL CHARACTER OF THE ROCK.

Six thin sections were prepared from selected chips of the rock for microscopical study. Five of the sections were cut from the nodules and one from a representative fragment of the interstitial filling or matrix. The character of the sections was such that only slight evidence was afforded of the structure of the nodules microscopically, but the radial arrangement of the minerals composing the nodules about a common center is entirely clear in hand specimens of the rock, as indicated in the megascopic description above and shown in Fig. 2.

Diallage, green hornblende, basic plagioclase, microcline, quartz, titanite, muscovite, calcite, zoisite, magnetite, and an occasional zircon are the principal minerals of the rock. Essentially the same minerals are observed, as a rule, in both the matrix and the nodules, but in different proportions; the matrix being composed very largely of feldspar, with very subordinate amount of most of the other minerals, and the nodules of the ferromagnesian minerals, with in many of them only the barest trace of the other minerals. Of the accessory minerals noted in the nodules feldspar is usually in largest amount.

The ferromagnesian minerals, diallage and hornblende, in varying amounts are present in all the sections. In many of them, probably a majority, hornblende is subordinate in amount to diallage; in others the two are in nearly equal proportion; and in still others

hornblende is in slight excess. Diallage occurs in rather large irregular forms without crystal boundaries, exhibiting strong development of the orthopinacoidal cleavage. It is usually of faint greenish color and without sensible pleochroism. Minute microscopic interpositions are abundant, and it further incloses irregular grains and perfect idiomorphic crystals of hornblende.

The hornblende is principally of the green uralitic kind, approximating parallel columnar and fibrous forms, which usually show cleavage only in direction of elongation, but it entirely fails in some of the more irregular aggregates. Both the hornblende and diallage indicate some alteration (leaching) to nearly colorless forms. The angle of extinction measured on many pieces of the hornblende varies from 13° to 20°. Pleochroism is confined chiefly to green tones, with the ray vibrating parallel to A appearing slightly yellow, and that vibrating parallel to B is occasionally tinged a faint brown. Compact hornblende in rhombic cross-sections, bounded by the prism and usually the pinacoid faces, and showing the intersecting prismatic cleavages, is distributed through the sections, with much of it inclosed by the diallage.

Basic plagioclase is the predominant feldspar. Its substance is never fresh, but is largely altered to muscovite and calcite, and some zoisite which, with few exceptions, has completely destroyed the polysynthetic twinning lamellæ. It occurs almost entirely as irregular, large grains without idiomorphic outline. Perfectly fresh microcline as irregular grains, and exhibiting the characteristic twinning structure, is present in every thin section studied. It sometimes occurs as inclusions of moderate-sized grains in the plagioclase. Abundant prisms of apatite, usually of fairly large size, are included in the feldspar. Some of these are in cross-sections which show perfect hexagonal shape; others are in longitudinal sections, and occasionally some of the apatite forms grains of irregular outline.

Titanite is abundant in comparatively large idiomorphic crystals, yielding characteristic, sharply rhombic cross-sections. Some of it occurs in irregular grains without crystal outline. In thin section the color is pale to moderately deep brown, with slight absorption in the deeper-colored crystals. It is usually free from inclusions of other minerals. Cleavage is rather pronounced in much of it.

Quartz is present in very subordinate amount in many of the sections, and it is probably largely, if not entirely, secondary. Muscovite and calcite are wholly secondary, and as such they present no noteworthy features. Magnetite and an occasional zircon complete the list of minerals.

Summing up the results of the microscopic study, we find that the sections consist essentially of diallage, uralitic hornblende, and a basic plagioclase, showing, as a rule, but slight polysynthetic twinning, and usually altered to muscovite and calcite, or to zoisite and muscovite. The presence of perfectly fresh microcline in subordinate amount, a little quartz which is probably secondary, and a relatively large amount of accessory titanite and apatite is characteristic. Clearly the rock is a gabbro-diorite, although the presence in some of the sections of microcline and quartz is unusual.

ORIGIN OF THE NODULAR STRUCTURE.

Bäckström accounts for the origin of certain European nodular granite on the basis of magmatic differentiation, in which the nodules, like the Carolina occurrence, are more basic than the matrix.[1] This seems to be the most satisfactory explanation of the Carolina occurrence, but whether the beginning of the nodules resulted from greater basicity, differential cooling, or from some other cause, it is not possible to state definitely.

From the relations of the minerals in the rock it appears that the dark silicates generally preceded the feldspar in crystallization, although overlapping in the periods of separation from the magma of these minerals is distinctly shown. The primary accessories, apatite, titanite, iron ore, etc., are idiomorphic in outline and were the earliest minerals to crystallize from the magma. Microscopic evidence further indicates that the nodules were developed in the magma when crystallization was fairly well advanced.

RÉSUMÉ.

Briefly summarized, the principal results of this study are: (1) The rock is a gabbro-diorite whose field relations strongly suggest occurrence in the form of a dike penetrating a gray porphyritic biotite

[1] JOURNAL OF GEOLOGY, Vol. I (1893), pp. 773–90; *Geologiska Föreningen i Stockholm, Förhandlingar*, 1894, p. 128.

granite. (2) Two textural facies of the rock having approximately the same mineral composition, are observed, namely, (*a*) orbicular or nodular, and (*b*) granitic. (3) In the nodular facies the nodules compose vastly the greater bulk of the rock. They are of varying, but moderately large, size, usually crowded close together, with a small amount of matrix or interstitial filling, largely composed of feldspar and very subordinate amount of the other minerals. (4) The nodules are uniformly dark in color, very basic in composition, and, with but few exceptions, are made up almost entirely of the dark silicates, diallage, and hornblende. (5) The structure of the nodules is radial and not, as frequently observed in such rocks, concentric, or both. (6) Microscopic evidence suggests that the nodular structure is a product of magmatic differentiation.

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THE OSTEOLOGY OF THE SKULL OF THE PELYCOSAURIAN GENUS, DIMETRODON.

During the summer of 1904 the author collected in the Permian beds of Texas two skulls of the genus *Dimetrodon* belonging in the suborder *Pelycosauria*. These skulls were in an excellent state of perfection, which permits the completion of previous descriptions and the correction of some errors.

Especially valuable is the fact of the preservation of the temporal arches, permitting a description of this region, which has been hitherto only partially known and falsely interpreted. The two skulls are numbered 1001, *Dimetrodon incisivus* (?), and 1002, *Dimetrodon gigas*, of the University of Chicago collection of fossi vertebrates. The specimen of *Dimetrodon gigas* was almost perfectly preserved, only a portion of the temporal arches of the left side and the middle portion of the epipterygoid being lost. The larger part of the following description is taken from it; some details, and the description of the lower jaws, are added from specimen 1001.

As shown in Fig. 1, the skull has proportions much like those of the modern lizards or the carnivorous Dinosaurs. The eyes are not located so far back in the head, and the facial region, while elevated, does not bear the great disproportion to the skull shown in previous restorations.[1]

The quadrate of *Naosaurus* was correctly interpreted by Cope as an elevated element similar to the same bone in the modern *Sphenodon*. This was later denied by Baur and Case,[2] and the statement was made that the quadrate was a depressed bone completely surrounded by the bones of the temporal region, and in this regard similar to the African Theriodonts.

[1] E. D. Cope, "On the Homologies of the Posterior Cranial Arches of the Reptilia," *Transactions of the American Philosophical Society*, Vol. XVII (1892); G. Baur and E. C. Case, "On the Morphology of the Skull of the *Pelycosauria* and the Origin of the Mammals," *Anatomische Anzeiger*, Vol. XIII (1897), pp. 109–20; *idem.*, "The History of the *Pelycosauria*, with a Description of the Genus *Dimetrodon*," *Transactions of the American Philosophical Society* (2), Vol. XX (1899), pp. 1–58.

[2] *Op. cit.*

The determination was made on a partially preserved skull of *Dimetrodon incisivus*, and a series of unfortunate conclusions have been drawn from this erroneous determination. The present specimens show that Cope was correct in his determination of the quadrate as an elevated bone, and also demonstrates its remarkable similarity in position and relations to the quadrate of *Sphenodon.*

Figs. 1, 2, and 4 show the general form and relation of the quadrate. It is an elevated, thin plate of bone ending freely above, articu-

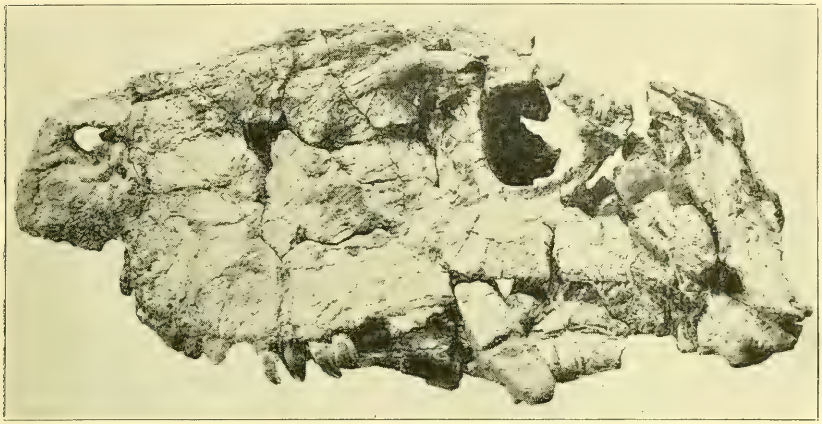

FIG. 1.—Left side of the skull of *Dimetrodon gigas.* About one-fourth natural size. Full length of skull, 46 cm.

lating with the pterygoid anteriorly, and the quadrato-jugal, squamosal and paroccipital posteriorly. The lower end is terminated by two elongate articular condyles, which run almost parallel antero-posteriorly, but are slightly convergent anteriorly. The inner condyle stands out from the side of the bone, and its inner side articulates with the posterior end of the pterygoid. The outer condyle projects beyond the posterior edge of the bone, and its upper surface is flat, forming a sort of shelf, to the upper side of which is articulated the lower end of the quadrato-jugal.

The quadrato-jugal is a very slender plate of bone that articulates with the posterior edge of the quadrate for its full length. Above, the quadrato-jugal passes between the squamosal and prosquamosal, and articulates with the parietal; below, it is separated from the quadrate by a fair-sized quadrate foramen.

Anterior to the quadrato-jugal is another element in the position usually assigned to the quadrato-jugal; *i. e.*, it articulates with the jugal anteriorly and passes back to articulate with the quadrate region. It is separated from the quadrato-jugal posteriorly (which is identified beyond doubt by the presence of the quadrate foramen) by a distinct suture, and occupies the exact position of the anterior portion of the squamosal of the living *Sphenodon*. It is separated from

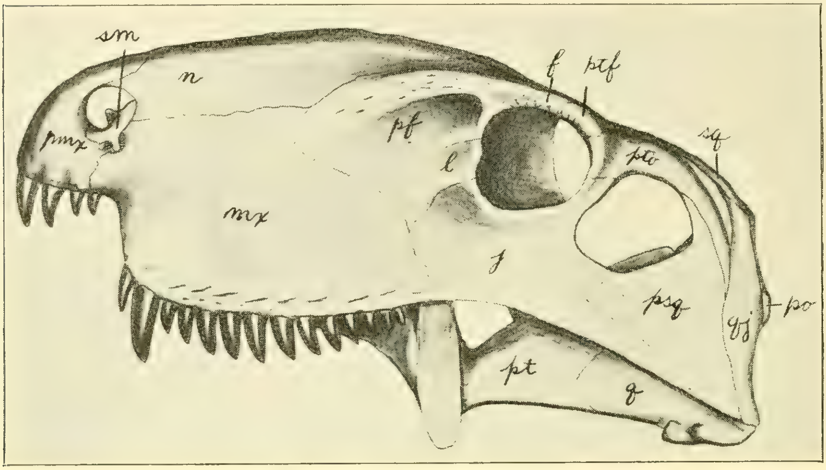

FIG. 2.—Restoration of the left side of the skull of *D. gigas*. *bo*, basi-occipital; *bs*, basi-sphenoid; *f*, frontal; *j*, jugal; *l*, lachrymal; *mx*, maxillary; *n*, nasal; *pmx*, pre-maxillary; *pv*, prevomer; *pt'*, ascending plate of pterygoid; *pt*, pterygoid; *pf*, prefrontal; *ptf*, postfrontal; *pto*, postorbital; *pa*, parasphenoid; *psq*, prosquamosal; *ps*, ethmoid; *po*, paroccipital (opisthotic); *q*, quadrate; *sq*, squamosal; *st*, stapes.

the squamosal above by the meeting of the quadrato-jugal and parietal; but if these were to separate, and the squamosal and this element came in contact or fuse, we should have the exact condition of the primitive *Rhyncocephalia* (*Saphaeosaurus*), or *Sphenodon*. For this reason I have determined the bone as the prosquamosal. This bone articulates posteriorly with the postorbital, quadrato-jugal, and the lower extermity of the parietal.

The inferior temporal vacuity is formed by the jugal, prosquamosal and postorbital. It is nearly as large as the orbit. The superior temporal vacuity is formed by the postorbital, prosquamosal, quadrato-jugal, and parietal. It is very small, amounting to a small

slit in the *Dimetrodon gigas* No. 1002, and is even doubtfully open in the *Dimetrodon incisivus* (?) No. 1001. The edges of the bones adjacent to the opening are thinned,and in case where the opening is uncertain there is clear evidence of the thinness of the roof of the skull. If this superior temporal opening is just appearing, as seems certain, we have confirmatory proof of the origin of the temporal arches by a process of natural trephining of the completely roofed skull, as proposed by Baur. It is important to notice that the bones

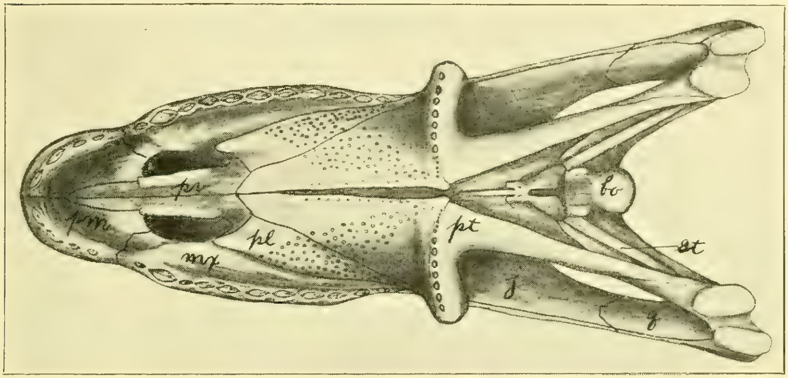

FIG. 3.—Palatal view of the same skull. Letters as in Fig. 2.

have arranged themselves in the position of the perfect arches before the openings appear.

On the posterior face of the skull the remnants of fairly strong stapes was found in position. Unfortunately, neither end was preserved, so that it is impossible to confirm Cope's description of the anterior end of the Pelycosaurian stapes.

On the inferior face of the skull the position of the pterygoids and other bones is confirmed, but the external processes of the pterygoids are shown to have been located farther forward than supposed—at the posterior end of the maxillaries. It is determined that there were no posterior palatine openings between the palatine and maxillary. Anteriorly the nares are separated by the paired prevomers; the sides of the prevomers are marked by rugosities at the inferior opening of the nasal canal.

The ectopterygoid (transverse) is made out for the first time. It is a short bone, articulating with a strong, curved ridge on the inner

side of jugal, which at its lower end becomes sessile, and anteriorly with the maxillary. It covers the anterior and the upper portion of the outer process of the pterygoid.

The bones of the facial region are very similar in position to those of previously described specimens, but there is shown a separate bone at the anterior end of the nasal, forming the posterior wall and a portion of the floor of the external nares. This occupies the same position as the bone called the septo-maxillary in *Sphenodon* by Howes and Swinnerton.[1] The bone has a very peculiar form, being bent at right angles so that the anterior portion forms the posterior half of the floor of the nares, and the posterior half forms the posterior wall. The two bones of the opposite sides meet in the median line, so that they would close the nares; but the inner part of the posterior half is only one-half as high as the outer, so that the inner opening of the nares is elevated. The air entering the nares could not pass directly backward or downward, but first rose over the half partition, and then down into the mouth. The lower edge of the septo-maxillary joins the maxillary and premaxillary. The suture between maxillary and septo-maxillary is marked by two foramina.

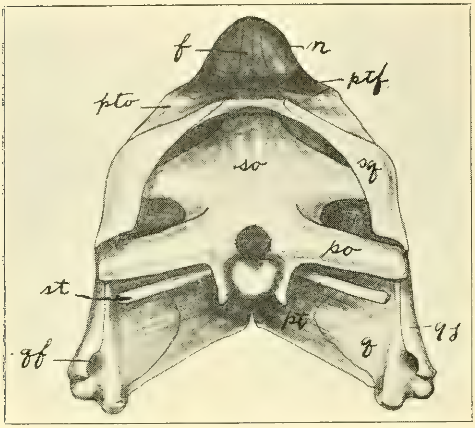

FIG. 4.—Posterior view of same skull. Letters as in Fig. 2.

The section of the skull shows several peculiar conditions. There are paired prevomers which are anteriorly united with the premaxillaries. Passing backward, they are convex upward, so that the anterior portion of the mouth is vaulted. Opposite the maxillary-

[1] G. B. HOWES AND H. H. SWINNERTON, "On the Development of the Skeleton of the Tuatera *Sphenodon* (*Hatteria*) *punctatus*," *Transactions of the Zoölogical Society of London*, Vol. XVI (1903), Part I, No. 1, pp. 1–87, Plates I–VI, Figs. 18.

premaxillary suture the prevomers are free from the side walls of the skull, leaving the elongate openings of the posterior nares. The sides of the posterior nares are marked on the prevomers by rugose ridges. The prevomers are united on the lower surface, but the upper portion is divergent, and receives anteriorly the lower edges of two vertical plates that seemingly originate from the inner edges

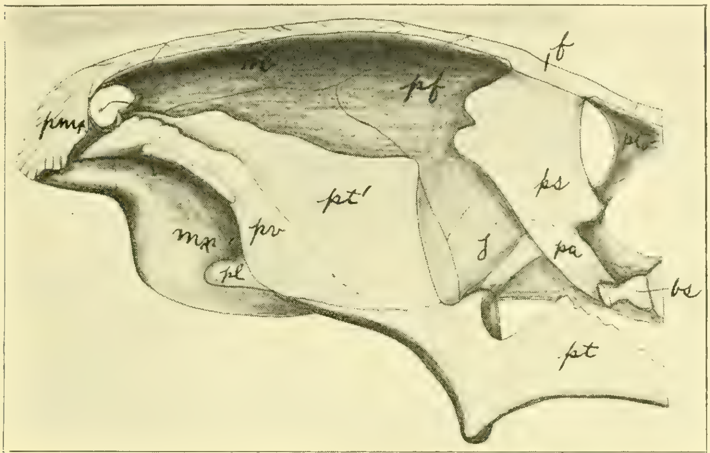

FIG. 5.—Section of the same skull showing septal bones. Letters as in Fig. 2.

of the pterygoids and extend directly upward in the skull. Owing to the somewhat crushed condition of these very slender plates, it is impossible to tell exactly the point of their connection with the prevomers below, but apparently they lie between them, and there was either a squamous contact, or the bones were free in life and have been crushed together in fossilization. The origin of the two vertical plates is somewhat obscure. They occupy the position of vomers behind the prevomers, but the true vomer is a single median bone, and, moreover, is accounted for. Broom[1] has described in *Proterosuchus* two slender vertical plates rising from the inner edges of the pterygoids, with a single median vomer between. It seems that these plates must be the same sort of a structure. They occupy

[1] R. BROOM, "On a New Reptile (*Proterosuchus fergusi*) from the Karoo Beds of Tarkastad, South Africa," *Annals of South African Museum*, Vol. IV (1903), Art. 7.

exactly the same position, but are relatively much larger than figured by Broom.

Posteriorly the parasphenoid is much reduced, and is attached as a slender vertical plate of bone to the anterior end of the basisphenoid between the basiptergoid processes. Above, the parasphenoid articulates directly with a thin vertical plate of bone which expands antero-

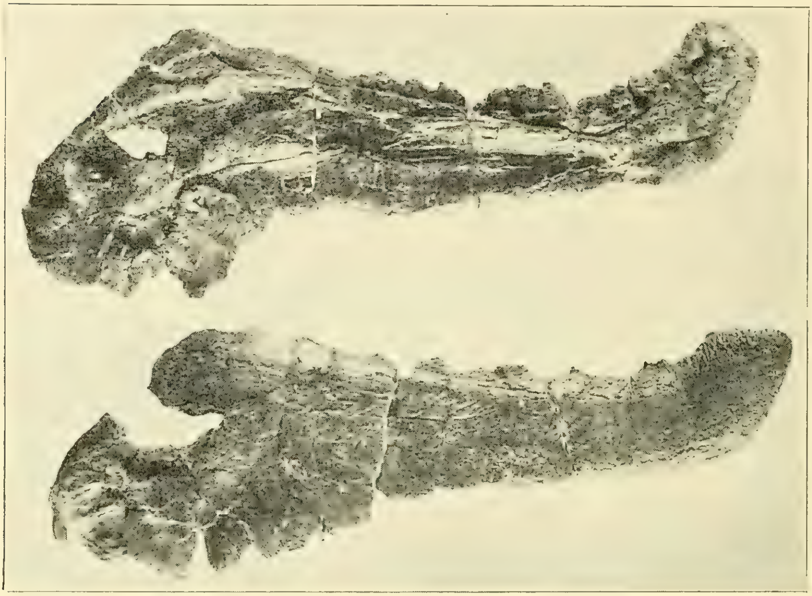

FIG. 6.—Lower jaws of *Dimetrodon incisivus* (?), showing the inner and outer surfaces. Full length of jaws, 33 cm.

posteriorly as it rises in the skull, and finally articulates in the median line with the under side of the frontals. This bone can only be the ossified ethmoid portion of the median cartilaginous septum. The anterior edge of the ethmoid is somewhat irregular and thin, and represents the true vomer; the posterior inferior angle is rounded and thickened and there is an excavation which evidently marks the exit of the II nerve from the skull. The presence of a median septum of this character is very peculiar in view of the fact that there are well-developed epipterygoid bones indicated by the preserved lower ends in contact with the posterior portion of the pterygoids.

There was no sign of the lower jaws with the skull of *Dimetrodon gigas*, but with the other skull, No. 1001, the jaws were preserved nearly perfectly. They show that the portion identified by Baur and Case as the articular region of the skull is in reality the articular region of the lower jaw. The articular is small and nearly inclosed by other bones. Its upper face is marked by two deep cotyli, and the posterior edge in specimen No. 1001 has a small hook-shaped projection. The quadrate is supported by the angular, surangular, and splenial (Baur), prearticular (Williston). The posterior ends of these bones stand out from the thin expanded posterior end of the bone, supporting the articular bone on a sort of pedicel instead of on the upper edge of the jaw. This explains why the articular region is so often found isolated in the fossil beds. The posterior portion of the jaw is very thin, but expanded vertically. In both jaws the coronoid bone is lost, but it was a small, thin plate, as shown by the sutures for its attachment. Anteriorly the angular passes far forward, forming the posterior half of the outer side of the jaw. The splenial or prearticular reaches nearly to the middle of the jaw, where it disappears under the splenial (presplenial of Baur). The spenial reaches to the symphasis, but does not take part in it.

As previously described, there are enlarged incisor and canine tusks in the upper jaw, and enlarged incisors in the lower jaw. In *Dimetrodon gigas* the edges of the teeth are crenate, but this and the number of the teeth in the jaws seem to be somewhat variable in the different species of the genus.

In general, the whole skull may be said to bear a remarkable resemblance to the skull of *Sphenodon*, in most parts being directly comparable to it, and varying only in the temporal arches—the ossified interorbital septum, and the vertical plates of the upper side of the pterygoids.

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ON THE STRUCTURE OF THE FORE FOOT OF DIMETRODON.

DURING the summer of 1903, while in charge of the University of Chicago expedition in the Permian fossil fields of Texas, the author collected the right fore leg and foot of a Pelycosaurian reptile of the genus *Dimetrodon*. The species is not determinable at present, but is very close to *Dimetrodon incisivus*, if not that species exactly. When found the bones were badly softened by decay, but after cleaning and hardening I find that those of the carpus, with one exception, are perfectly preserved and in their natural positions. This is particularly fortunate, as it is the exception to find any considerable portion of a skeleton together in the Texas fields.

The author has previously described[1] an imperfect front foot of *Dimetrodon*, No. 114 of the University of Chicago collection, and attempted to place the bones in their natural relations. The present specimen shows that the position of the bones in the figure was erroneous and must be corrected.

Fig. 1 shows the right front foot from the lower surface. The bones added from another specimen are in line only. The specimen has received the number 1003 in the University of Chicago collection of vertebrate fossils.

A study of the specimen brings out first of all the striking resemblance of the foot to the foot of *Sphenodon* (Fig. 2), not only in the number of the bones, but in the arrangement and to some extent the form. This emphasizes the Ryhnchocephalian nature of the Pelycosaurs already demonstrated from the structure of the skull.

The carpus consists of eleven elements. The ulnare is a stout bone with wide proximal end, and resembles the same bone in *Sphenodon* very closely. The radiale is larger than the ulnare, but is not so stout; it is very thin, but elongate and articulates with the distal row of carpals. The intermedium reaches well up between the radius and ulna. There are two centrale. Centrale 1 occupies a central

[1] JOURNAL OF GEOLOGY, Vol. XI, No. 1 (1903), p. 11.

position in the carpus and is much larger than the second. Centrale 2 lies between the ulnare and the third, fourth, and fifth carpals, but is surrounded by bones, as its outer side articulates with the sesamoid. The form and articulation of the five carpals of the distal row are best

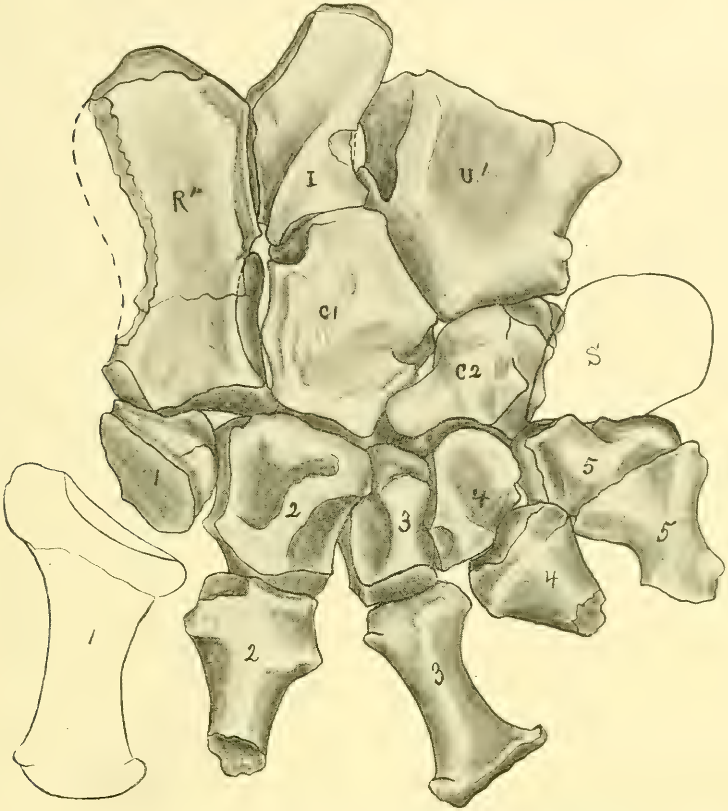

FIG. 1.—Lower side of the manus of the right foot of *Dimetrodon* sp. *r'*, radiale; *u'*, ulnare; *i*, intermedium; *c* 1, centrale one; *c* 2, centrale two; *s*, sesamoid; 1, 2, 3, 4, 5, carpals and metacarpals. Natural size.

seen from the figure. The fifth carpal is peculiar in its prominent position at the side of the carpus, standing well away from the rest of the bones.

A second specimen of *Dimetrodon* discovered the same summer afforded a nearly complete anterior portion of the skeleton. It has received the number 1001 in the Chicago collection. The bones of

this specimen were somewhat scattered, so that, although the bones of the fore legs and feet were preserved, they were not in position. From the specimen 1003 the bones of the carpus of both sides in specimen 1001 have been placed in position, and both show the presence of an extra element which, from the position of articular surfaces and from comparison with *Sphenodon*, evidently occupies the position of the pisiform bone on the ulnar side of the mammalian carpus. It is a sesamoid bone of considerable size.

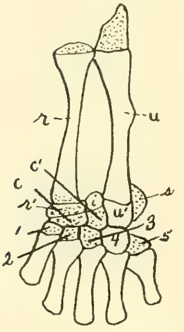

FIG. 2.—Upperside left manus of *Sphenodon* after Bayer and Howse, from Osborn. Lettering as in Fig. 1. Natural size.

The bones of the carpus fit snugly together, with well-developed articular surfaces, making a strong foot. This is also shown by the possession of well-developed phalanges and powerful claws.

The first digit was shorter and stouter than the second. The broad proximal end is characteristic of the first metacarpal. The second digit was probably the largest of the foot, judging from the length of the metacarpal and the imperfect foot of specimen 114. The third and fourth metacarpals are more slender than the second. The fifth metacarpal is a very broad and thin bone articulated to the prominent fifth carpal, so that it stood out from the others at a considerable angle. The articular surface between the fifth carpal and metacarpal is twisted in a peculiar manner, so that it permits of a considerable range of motion. This perhaps explains the fact that the fifth metacarpal and digit were found in the specimen 114 lying at right angles to the fourth. In the description and figure of 114 they were called first and second.

FIG. 3.—Manus of *Procolophon*. From Osborn after Broom. Lettering as in Fig. 1. Natural size.

It is interesting to compare the carpus of *Dimetrodon* with the carpus of *Procolophon* in the light of Broom's determination of the *Rhynchocephalian* nature of *Procolophon*.[1] Fig. 3 is an outline

[1] BROOM, *Records of the Albany Museum*, Vol. I, No. 1 (1903). See also OSBORN, *Memoirs of the American Museum of Natural History*, Vol. I, No. 8 (1903), p. 480.

drawing of Broom's restoration, slightly modified according to Osborn; *i. e.*, the bone marked centrale 2 was called by Broom radiale. It will be seen that the carpus is essentially the same if the radiale is restored. The fifth carpal is missing, but that may well be left open for future evidence, as there is so commonly a fifth carpal in the primitive reptiles.

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Milwaukee, Wis.

ON THE PYROXENITES OF THE GRENVILLE SERIES IN OTTAWA COUNTY, CANADA.

THE pyroxenic rocks associated with the apatite deposits, and by Hunt[1] called pyroxenites, constitute an important feature of the Grenville series over considerable areas north of the Ottawa River in Canada. There has been a wide divergence of views as to their origin, some regarding them as metamorposed sediments, while others consider them to be of igneous origin. The observations of the writer support the latter view. They were made in the vicinity of High Rock, an apatite mine, situated on the right bank of the Du Lièvre River about twenty-one miles above Buckingham and forty miles north of Ottawa. The openings here cover about six hundred acres in all on the tops of the hills which rise to a height of seven hundred feet above the level of the river. The longer axes of the hills trend south 40° east parallel with the strike of the rocks of the region. The apatite occurs in veins or pockets in the pyroxenite or along the contact of the pyroxenite with dikes of syenite which cut it in various directions. As described by the writer,[2] this dike rock varies from a course-grained syenite to a rather fine-grained gneiss. As an intermediate stage there occurs at a number of places, both on the surface and associated with the apatite in the diggings, a peculiar spheroidal phase of the syenite, called "leopard rock," which is considered due to dynamic processes.

The pyroxenites usually occur in parallel bands intercalated in the quartzites, though they sometimes cut across the bedding of the latter. Fig. 2 represents the relations of these rocks as seen at one locality on the hill. The pyroxenite bands, which have the appearance of an intrusion in the quartzite, have suffered breaking and stretching, while quartzitic material has taken possession of the spaces between the disrupted blocks. Still better are these relations shown in Fig. 3. At this locality the pyroxenite appears in the main to have

[1] *Geology of Canada*, 1866, p. 185; *Chemical and Geological Essays*, p. 208.

[2] *Bulletin of the Geological Society of America*, Vol. VII, pp. 95–134.

followed the bedding of the quartzite, but in places it has broken across it and has involved considerable portions of the quartzite within itself. The rocks strike south 40° east and are cut by joints

FIG. 1.—Syenite Gneiss from dikes cutting the pyroxenite at High Rock mine, Ottawa county, Canada. (1) Shows the coarse-grained phase of the Syenite, (2), (3), and (4) represent the Leopard Rock phases, and (5) the gneissic phase.

having a general direction of north 70° west. As shown at the upper left corner of the cut, the jointing is more pronounced in places along the contact with the pyroxenite. Both rocks are cut by small dikes

or stringers one-half to one inch in width, one (*a*) consisting of basic (probably hornblendic), and the other (*b*) of feldspathic material. In places masses of the pyroxenite appear as inclusions in the syenite dikes, and without close examination might easily be taken for a segregation of basic material in the syenite.

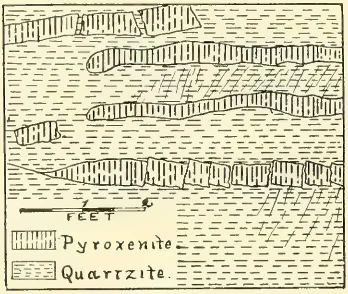

FIG. 2.—Showing pyroxenite intercalated in the quartzite.

Under the microscope the pyroxenite is shown to consist chiefly of a pale, almost colorless monoclinic pyroxene, apparently augite. It is for the most part coarsely crystallized and has a pronounced prismatic cleavage. Polysynthetic twinning in thin lamellæ parallel to the orthopinacoid (100) is frequent, giving a pronounced diallage-like appearance, probably due to the development of gliding planes as a pressure phenomenon.[1]

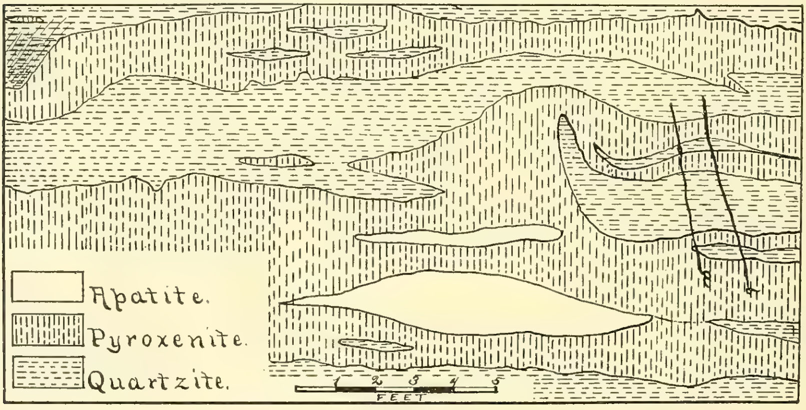

FIG. 3.—Showing the pyroxenite interbedded with the quartzite and including portions of the latter.

Further evidence of dynamic movement appears in the slight lack of correspondence in the continuation of cleavage cracks, in the bending and fracturing of lamellæ, and especially in the extinction shad-

[1] F. ZIRKEL, *Lehrbuch der Petrographie*, Vol. I, p. 612.

ows, though the last are more easily distinguished in the larger grains. The lamellæ are usually thin, varying from extreme fineness to 0.013 ^{mm} in thickness. In sections parallel to the clinopinacoid (010) the extinction angles of the lamellæ measured from 38° to 43°, and none were found to extinguish parallel, thus precluding the possibility of an intergrowth of augite and hypersthene. (Fig. 4.)

Along with the augite there occur as minor constituents in varying, usually small, proportions, scapolite, quartz, apatite, brown mica, hornblende, and an opaque iron ore.

FIG. 4.—Section of pyroxenite. *A*, augite; *Ap*, apatite inclosing small prisms of zircon; *S*, scapolite; *T*, titanite.

The scapolite has a cloudy, yellowish-gray, fibrous appearance usually, and in places occurs in considerable amount in graphic intergrowth with the augite. This is especially the case near the contact of the pyroxenite with the syenite-gneiss. An analysis of the scapolite by William Hoskins gave the following results:

SiO_2	50.230
Al_2O_3	27.207
FeO	11.123
CaO	8.175
MgO	1.732
	98.464

This indicates a high percentage of iron, with a correspondingly low showing of lime, possibly attributable to the altered condition of the material.

Apatite appears in considerable amount as irregular grains and aggregates. In some cases the pyroxenite and apatite are found in

alternating parallel lamellæ resembling eozoon and sometimes mistaken for it.

The mica is usually confined to the portions showing a laminated structure where it occurs in considerable amount along certain planes.

Titanite occurs in occasional grains, showing the usual chocolate brown color and well-marked development of gliding planes parallel to (221) characteristic of American sphenes.[1]

The hornblende which is small in amount is compact and strongly pleochroic. It is usually in close connection with the augite, and the relations of the prismatic cleavages are sometimes such as to indicate that the ortho- and clino-pinacoids of the two minerals lie parallel.

ORIGIN OF THE CANADIAN PYROXENITES.

Various opinions have been expressed as to the origin of the Canadian pyroxenic rocks. Much has been written concerning the origin of the apatite deposits which occur in them, but it is manifest that any conclusion regarding these would be shaped, in part at least, by the view held concerning the origin of the pyroxenites themselves. The occurrence of the pyroxenites in bands alternating with the quartzites and gneisses simulating bedding has led some writers to regard them as of sedimentary origin. When first used by Dr. Hunt, the term "pyroxenite" was applied both to rocks which have been recognized as intrusive, like those of Rougemont and Montarville, and to the more or less massive beds or nests of pyroxene so often intercalated in the so-called Archean limestones of New York and Canada.[2]

Concerning the latter, Hunt states that they grade, on the one hand, into granitoid orthoclase gneiss and, on the other, into limestone, and concludes that "these peculiar strata, which contain at the same time the minerals of the associated gneiss and of the limestone, may be looked upon as beds of passage between the two rocks."[3] They were regarded by this author[4] as having been deposited originally

[1] G. H. Williams, *American Journal of Science*, Series III, Vol. XXIX, p. 486.

[2] G. H. Williams, *American Geologist*, Vol. VI (1890), p. 45.

[3] T. J. Hunt, *Geology of Canada*, 1866, p. 185.

[4] *Chemical and Geological Essays*, 1891, p. 305.

as amorphous chemical sediments, which under moderate heat and pressure arranged themselves and crystallized, generating the various mineral species by a change which Gümbel designates *diagenesis*. The apatite deposits were regarded by Hunt[1] as vein formations resulting from hot-water solutions, though some were thought to occur in beds. The belief as to the vein origin of these deposits was based on the following considerations: (1) the rounded form of the apatite crystals, which he considered due to partial solution after deposition, rather than to fusion in a molten magna; (2) the manner in which one mineral incloses another, as in the case of crystalline calcite, rounded into pebbles and inclosed in the center of apatite crystals; (3) the banded structure observed in some deposits; (4) drusy cavities. The banded arrangement is not a frequent characteristic of the deposits, but is sometimes seen. Dawson considers many of the Ontario deposits as true beds and of organic origin, thus apparently postulating a sedimentary origin for the inclosing rocks,[2] though not necessarily for all of them.

Harrington, in his admirable report on the apatite-bearing veins of Ottawa county, takes the same view as to the origin of the pyroxenites, and contends that the conclusions of Brögger and Reusch concerning the eruptive origin of the apatites of Norway do not apply to the Canadian occurrences. He adds:

> The pyroxenites often contain disseminated grains of apatite, and no doubt they are the strata from which the apatite of the veins has been chiefly derived. If, as has been suggested, the apatite of these ancient strata represents material accumulated by organic agencies, then the connection of the pyroxene and apatite may be that the former constituted an ocean bottom particularly suitable for the life of the creatures which secreted the phosphatic matter.

W. Boyd Dawkins,[3] who visited this locality in 1884, adopts Harrington's conclusions, though he adds: "Were it not that it is bedded, it would pass muster as an eruptive rock." He concludes that the apatite deposits were formed in fissures in the Archean gneisses by hydrothermal or aquo-igneous action under conditions

[1] *Geology of Canada*, 1863 pp. 477, 644; *American Journal of Science*, 2d ser., Vol. XXXVII, p. 252; *Chemical and Geological Essays*, p. 208.

[2] Sir J. W. Dawson, *Quarterly Journal of the Geological Society*, Vol. XXXII (1876), p. 289.

[3] *Proceedings of the Manchester Geological Society*, December 2, 1884.

of heat and pressure of the same general sort as that by which the rocks themselves have been affected.

On the other hand, the eruptive origin of these rocks has been upheld by various writers. In 1884, in his report on the apatite deposits, Torrence[1] guardedly states that these rocks may be due to contemporaneous intrusion. The apatite is regarded as due entirely to segregation from the pyroxene rock and never of a bedded character. In 1884 Coste[2] contends strongly for the eruptive origin of the pyroxenite, while the apatite is looked upon as possibly due to emanations accompanying or immediately following the intrusion of the igneous mass.

Dr. Selwyn subsequently supported this view, and said: "They are clearly connected for the most part with the basic eruptions of Archean date."

R. W. Ells[3] holds that, contrary to the observations of earlier writers, the pyroxene rock is not interstratified with the gneisses and quartzites, but occurs in dike-like masses and bands, which sometimes cut across the regular stratification of the associated rocks, and at other times traverse these along the bedding planes for some distance, and then abruptly change their course after the manner of other intrusives. In places, a gneissic structure is observed, but this, as in the case of the syenite, is doubtless due to great pressure. The author concludes that the apatite may be due to vapors charged with phosphoric and fluoric acids ascending along the sides of the dike.

The igneous origin of these pyroxenic rocks seems to be abundantly confirmed by their mode of occurrence at High Rock, as herein shown, and at numerous other places within the apatite district. While in general the pyroxenites extend along the bedding plane of the quartzites, they sometimes cut across the strike of these rocks after the manner of intrusions, as stated by Dr. Ells. In some places isolated lenticular masses of these rocks or a similar hornblende rock appear along the bedding plane of the quartzite, which are inexplicable except on the theory that they represent cross-

[1] *Geological Survey of Canada, Report of Progress*, 1882–83–84, Report J.

[2] *Ibid.*, 1887–88, Report S, p. 64.

[3] *Canadian Record of Science*, January, 1895.

sections of small offshoots from the main mass which have thrust themselves in between the beds of quartzite and were subsequently exposed by the planing down of the surface. Ells cites a number of cases where the pyroxenite cuts the stratified gneiss. At Little Rapids mine on Lièvre River the pyroxene dike is said to cut the banded gneiss at an angle of 30° or more. At North Star mine the

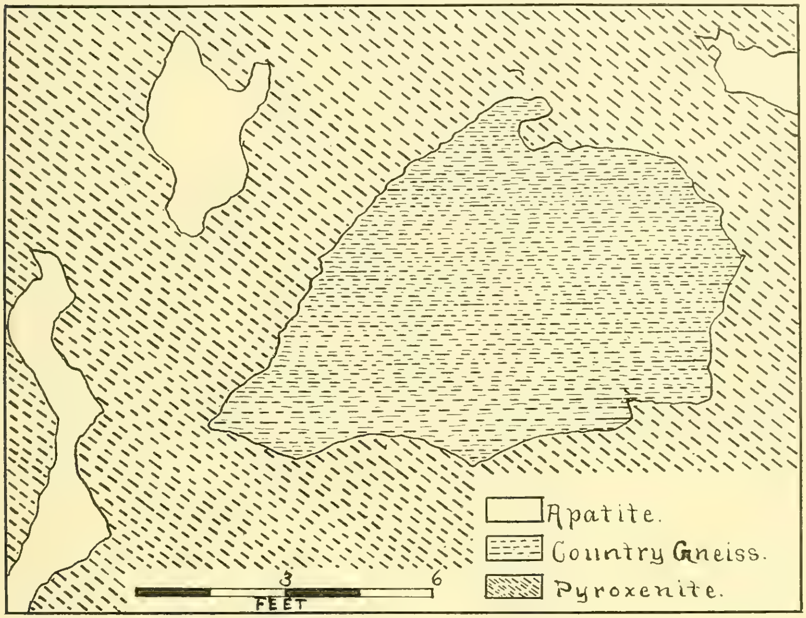

FIG. 5.—Bowlder of country rock imbedded in pyroxenite, High Rock mine, Ottawa county, Canada. (After Penrose.)

gneiss has been heaved up and bent around a portion of the dike, the contact of the two being sharply defined. A similar occurrence has been figured by Professor Penrose.[1]

That the pyroxenite should so often occur in sheets alternating with the quartzite is not strange, considering the extent of disturbance which these appear to have suffered and the more favorable conditions afforded by the bedding planes for the passage of the lava.

Further, and it would appear conclusive, evidence of the erup-

[1] R. A. F. PENROSE, "Nature and Origin of Deposits of Phosphate of Lime," *U. S. Geological Survey, Bulletin No. 46*, p. 25.

tive character of the rocks is found in the inclosures of country rock sometimes observed in them (Figs. 2 and 3). An occurrence of this kind at High Rock is noted in the above-cited report by Professor Penrose whose figure is here reproduced.

The evidence, therefore, clearly warrants the conclusion that the pyroxenic rock is intrusive. And that it represents the oldest intrusive is shown by the manner in which it is cut by the later intrusions of syenite and diorite, or so-called "trap."

NOMENCLATURE.

As heretofore stated, the term "pyroxenite" was first used by Dr. Hunt for an intrusive rock composed mostly of pyroxene with magnetite and ilmenite from Mount Royal and other places in Canada.[1] Later[2] he applied the name to the pyroxenic member intercalated in the limestones and quartzites of the apatite district, a rock generally regarded as having no genetic relationship with the first. Among the Canadian geologists it has come to be applied almost exclusively to the latter rock. Lacroix uses the term *gneiss à pyroxène et à wernerite* for a rock of essentially the same character from Brittany.[3] In the later work[4] Lacroix conforms to the German and English usage of calling this rock an "augite gneiss." These gneisses are said to occur in the upper part of the gneiss system, and are usually characterized by scapolite in greater or less abundance as in the Canadian rocks. The term "pyroxenite," which had previously been applied to these occurrences, is reserved by this author for rocks composed exclusively of pyroxene.

In 1890 G. H. Williams[5] used Hunt's term in its original signification for basic intrusions occurring in the eastern portion of the Piedmont Plateau in Maryland. These rocks are of a somewhat different type from the Canadian rocks, in that they are composed chiefly of an orthorhombic instead of a monoclinic pyroxene. Williams speaks approvingly of Lacroix's substitution of the term

[1] *Geology of Canada*, 1863, p. 667.

[2] *Catalogue of Canadian Rocks at Paris Exposition*, 1862; *Geology of Canada*, 1863–66, pp. 185–226.

[3] *Bulletin de la Société française de Mineralogie*, Vol. X (1887), p. 288.

[4] *Ibid.*, Vol. XII (1889), p. 83.

[5] *American Geologist*, Vol. VI (1890), p. 35.

"pyroxene-gneiss" for the French equivalents of the pyroxenic rocks occurring in beds or nests in the Grenville series, and contends that the Canadian use of the term "pyroxenite" for these rocks should be abandoned and the name restricted to non-feldspathic plutonic rocks free from olivine. The term is thus made a class designation co-ordinate with "peridotite," given by Rosenbusch to the corresponding olivine-bearing series, and the author says that its use as a designation for any rocks except those of igneous origin should be abandoned. As nearly all the Canadian pyroxenites were regarded by Williams, evidently on the authority of Hunt and others, as metamorphosed sedimentaries, they were excluded from the list. Zirkel[1] adopts Williams' classification, and includes these rocks with Lacroix's wernerite rocks under the pyroxene gneisses of the crystalline schists, apparently, though without distinct reference.

Pyroxenic rocks with augite as the chief basic mineral are not of common occurrence. Clements has described one from Alabama[2] which seems to be closely allied to these Canadian pyroxenites. In a comparison of the Ottawa pyroxenites with younger rocks, manifestly consideration must be given to the long period of time during which the former have been subjected to mountain-making forces.

As the result of this study we conclude:

1. That these pyroxenic rocks of Ottawa county were intruded into the overlying sedimentary beds at considerable depths, and solidified originally as a coarse-grained pyroxenite consisting chiefly of augite, but approaching the gabbro end of the series.

2. That, through the changes effected by pressure and metasomatic processes, whereby original structures have in large part disappeared, the rock should now be classed with the pyroxenite-gneisses.

3. That the apatite deposits associated with these rocks were due to fumarolic action at the time of the intrusion of the pyroxenites, and also, to a greater extent possibly, to that attending the later intrusions of syenite.

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[1] *Lehrbuch der Petrographie*, Vol. III, p. 149.

[2] *Bulletin 5*, Geological Survey of Alabama, p. 163.

A TYPICAL CASE OF STREAM-CAPTURE IN MICHIGAN.[1]

THE geographic relations of the phenomena to be described herein are shown in the accompanying map (Fig. 1). The wider relations are shown in the smaller map, the particular location being near Rawsonville, east of Ypsilanti, Mich.; while the more special relations are shown in the larger map.

The least modified and most typical remnant of the captured valley to be described is shown in Fig. 2—a view taken from the point *A* on the larger map, and embracing the upper part of what is now the Oak Run valley. The valley seen in the foreground has a typical trough-like configuration, with very definite slopes which make a distinct angle of 20° with the flat and marshy valley floor. No stream, however, flows through this portion. In the middle distance the valley floor terminates abruptly on the side of a deeper valley. The termination is given artificial distinctness by a roadway crossing at this point which has been raised about three feet on account of the marshiness of the valley floor. Nearly opposite this abrupt end of Oak Run valley, another valley, Oak Ravine, comes in obliquely from the right, as partially shown by the snow-covered slope near the group of elms in the middle of the picture. This valley heads in a clump of oaks, the tops of which are visible in the right background. The drainage of the valley is discharged opposite the truncated head of Oak Run valley. At the point of their nearest approach, in the left center of the view (Fig. 2), Oak Run and Oak Ravine are intercepted by an embayment of the Huron River flood-plain, whose bluffs are here about forty-five feet high. This embayment was made by a meander of the Huron River which cut back into the drift-plain of the region about a quarter of a mile, and reached the line of the two valleys in question (see map, Fig. 1). This drift plain constitutes the horizon in Fig. 2, and the bluff of the embayment is partially shown at the left below the barn.

[1] I am greatly indebted to Professor M. S. W. Jefferson for the accompanying photographs and for helpful suggestions in the preparation of this paper.

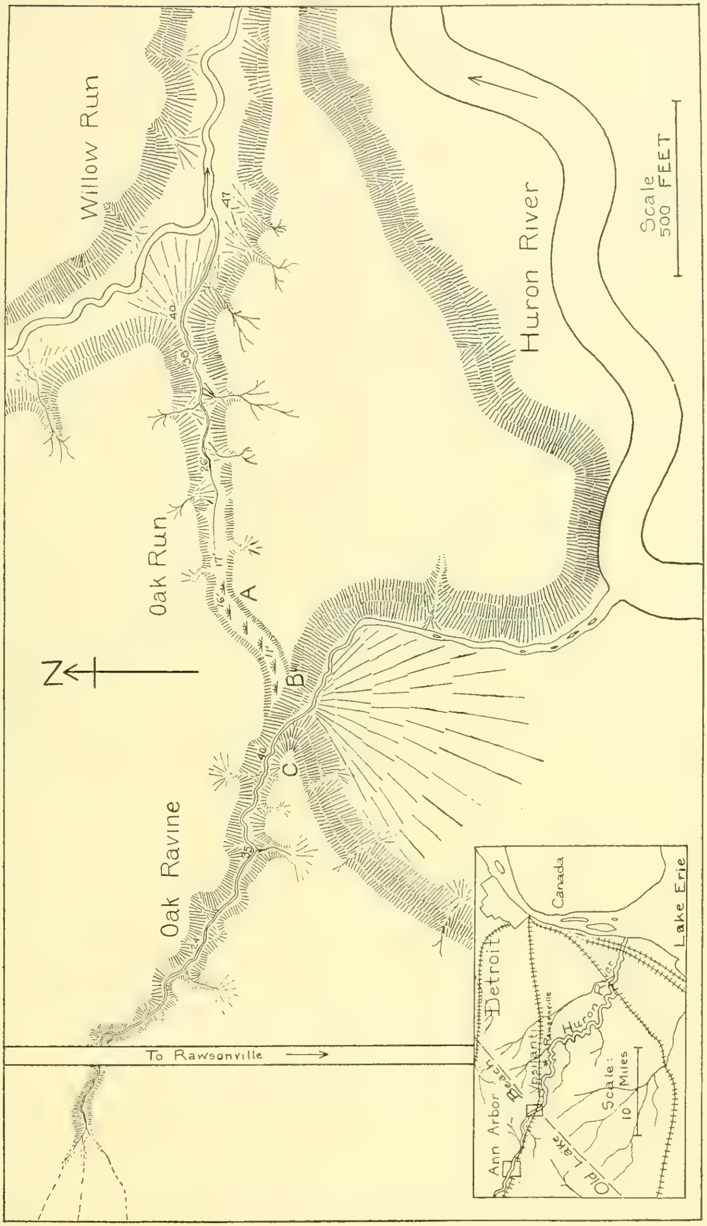

FIG. 1.—Map of Beheaded Oak Run.

When the encroachment of the bend of the Huron River began, Oak Ravine constituted the upper part, and Oak Run the lower part of a single valley, discharging into Willow Run; but when the right bank of their common valley had been broken down by the attack of the Huron, the waters of the headward portion were diverted and cascaded down the bluff of the embayment to the Huron below, while

FIG. 2.—Oak Run Valley where headwaters are taken out to left.

the part of the channel seen in the foreground of Fig. 2 was left a marshy flat. At the present time these two valleys, once continuous, have a difference of elevation of thirty feet, due to the erosion of the bottom of the upper section, while the head of the lower section has not been appreciably lowered.

The drainage area of the lower section, now the valley of Oak Run, is very small, probably less than 100 acres. The drainage area of the diverted upper section is several hundred acres. The difference in the erosion since the disseverance of the valley has brought the configuration of the two portions into sharp contrast. That of the lower portion at its head, where erosion has practically

stopped, has already been noted. That of the upper section, near its mouth, is shown in Fig. 3—a view taken from the point *B* on the map (Fig. 1) and looking westward up the valley.

The captured upper portion of Oak Ravine.—It will be noted that

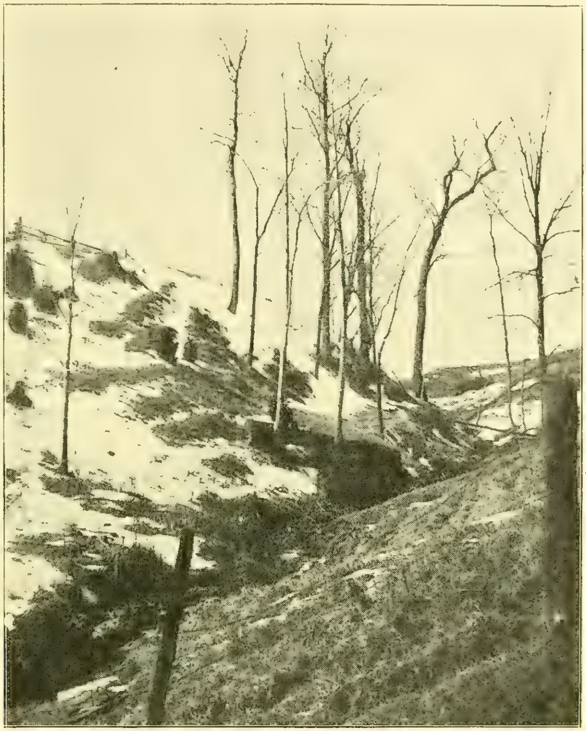

FIG. 3.—Oak Ravine—the deepened headwater valley of Oak Run.

this upper portion has the sharp characteristics of youth. The side slopes have angles as high as 25°. The stream in the bottom of the valley has no flood-plain, but hurries over rapids and little falls, giving evidence of decided youthfulness. Although pushed slightly to one side or the other by the alluvial fans built forward from the mouths of tributary gullies, it is in the main entirely competent to care for the waste creeping into it. The depth of the ravine below the upland is shown on the map at intervals of 250 feet by the numbers in the bottom of the ravine. It is seen from these numbers that

the profile of the descent is a normal curve, the flattest part being near the mouth and the steepest near the head of the ravine.

Out on the alluvial fan at the mouth of the ravine the stream finds a much gentler descent than it has previously enjoyed, and so begins to build up its bed, little sand-bars and islands showing the overloaded condition of the stream.

The heads of the tributary gullies have a characteristic amphitheatral shape. The slopes all lead to one central point from which the drainage follows a main course to the mouth of the gully. The waste slopes exhibit at present but moderate activity, although six or eight trees, prostrate because of undercutting, bear witness to the steady deepening of the ravine.

The beheaded valley, Oak Run.—The widths of the flat valley floor of Oak Run valley, expressed in feet, at intervals of 200 feet from the head, are as follows: 26, 22, 17, 16, 15, 10, 0. At the next to the last point given, Oak Run begins as a definite stream, and the valley floor gradually disappears, the valley becoming *V*-shaped, so that, standing at the mouth of Oak Run and looking upstream, one has a view similar to that shown in Fig. 3, and the stream here exhibits the same competency to remove waste, although no prostrate trees speak of great activity. On the map the numbers in the valley of Oak Run speak of abnormal valley descent, the flattest portion of the floored part of the valley being near the head. The steepening of the course continues until halfway down Oak Run, where the normal curve is assumed and maintained for the rest of the way.

The tributary gullies in the upper part of the valley have the same amphitheatral shape as those of Oak Ravine display, but farther downstream the dendritic pattern is assumed. The gullies have here gashed the upland deeply, and tons of earth are carried down them every year. Those at the head of the valley are long and gently sloping, and are gradually building up the valley floor. Those farther down push the weak stream from side to side until its increased volume enables it to pursue a more independent course. The greater part of the old watershed of Oak Run now drains into Oak Ravine, so that immediately after capture had taken place the now greatly diminished Oak Run began aggrading its valley-floor until the grade attained by the stream enabled it to carry all of the waste brought

in by tributaries and washed down from the valley sides. A part of the flat valley floor is thus accounted for; that near the head being explained by the fact that there is here no surface stream at all, but little waste has been removed, and the filling of the valley continues without interruption.

One of the clearest evidences of capture is the remnant of Oak Run valley perched on the Huron bluff and running neatly around

FIG. 4.—Looking down Oak Run from across mouth of Oak Ravine.

a spur into Oak Ravine. The bench-like effect which it gives to the bluff is very clearly seen in the field, although it appears but faintly in Fig. 2 because of the distance at which the view was taken. The bluff at the elbow of capture is covered over with tufts of grass and peat sliding down from the channel of Oak Run. Wet-weather gullies are eating farther and farther back, so that the bench will finally disappear. These facts unite with other evidence presented in indicating the extreme recency of the capture.

The whole case is so complete in detail and so small in size that it furnishes at once a perfect example of this kind of stream-adjustment

and an excellent pocket specimen, as it were, for classes in field geography. Since the discovery of this example of stream-capture, a study of the map reveals evidences of other cases near Ypsilanti which will be studied in the field during the spring and summer.

Relation to examples previously discussed.—The seizure of drainage areas of weak streams by more powerful adjacent streams forms an interesting phase in physiography. Broadly speaking, two forms of stream-capture may be recognized. The one takes place gradually through the headward growing of streams flowing down the steep inface of a cuesta, the captured stream originally flowing down the gentler outface. Gilbert describes such cases in his *The Geology of the Henry Mountains*, and Heim long ago pointed out the capture of the Inn by the steep-sloping Maira. To this class belong also cases later described by Professor Davis: the capture of the upper Schmiecha by the Eilach in the Swabian Alps, piratical Deer Run in eastern Pennsylvania, and a number of cases along the Blue Ridge of Tennessee.

Kaaterskill sheet, New York, of the U. S. Geological Survey, topographic sheets, shows Plaaterskill Creek undercutting the drainage areas of a southern tributary of Scoharie Creek; while a northern tributary is being undercut by the Kaaterskill. Both the Plaaterskill and Kaaterskill run directly into the Hudson, making a descent of about 900 feet in the first few miles of their course. Scoharie Creek drains northward into the Mohawk, and so finally into the Hudson, and must descend but 900 feet in at least fifty miles. It is therefore losing territory to the more vigorous streams gnawing into the eastern border of the upland.

The river systems of the Atlantic coast owe their present extension to westward cutting. One by one the streams of the Appalachian region have been diverted to the Atlantic, until but a single river continues its original course to the Mississippi. This is the Kanawha, wearing in canyon form the marks of its long struggle against the diverting tendency.

The second form of capture is accomplished by the sideways swinging of a master-stream, which may thus eventually eat into the side of a neighboring stream or behead one of its own tributaries. It may have been in this manner that the Red River came to enter the

Mississippi at Turnbull's Island, as shown on the eight-sheet map of the alluvial valley of the Mississippi. The Red may have run right to the Gulf at one time until the meandering Mississippi bit into the valley and carried off the waters. In time of drought, the Red discharges into the Mississippi, but in flood season it discharges partly into the Atchafalaya which runs into the Gulf. Bayous at Turnbull's Island indicate a possible westward meandering in the Mississippi sufficient to produce such a result. In the same way Bayou Maçon appears to have once discharged into the Tensas, and so into the Red, while Lake Maçon would seem to indicate that the Mississippi had cut into the river and captured it at that place. Eastward cutting in the Mississippi may then have carried the river away from Bayou Maçon, so that that stream now discharges through its old channel. Were it not for the extreme flatness of the Mississippi flood-plain, these streams would probably have continued to run into the Mississippi even after its withdrawal from the scene of capture. The silting up of the ends of the cut-offs seems on that faint grade to have been sufficient to return the streams to their old courses.

An example of capture from neighboring streams is that of the capture of the upper waters of Beaverdam Creek by the Shenandoah at Snickers Gap, as described by Bailey Willis; or the well-known capture of the upper Chattahoochee by the Savannah on the boundary between Georgia and South Carolina.

In the *National Geographic Magazine*, June, 1896, p. 189, in an article entitled "The Seine, the Meuse, and the Moselle," Professor Davis describes the capture of the Ste. Austreberte by the Seine, which, swinging past Quévillon and St. Martin, cuts into the bluffs bordering the upland at Duclair. The Ste. Austreberte is diverted from its previous course across the spur marked by the Forêt de Jumièges. The same writer describes a similar case on the Marne.

The Huron River exhibits the latter type of capture. During its youth it maintained a course, across what had been but recently the floor of a glacial-marginal lake, with strict propriety. Its tributaries flowed to the southeastward for the same reason as did the master-stream, and entered the Huron at a slight angle. The moment that the powerful Huron began swinging from side to side,

the integrity of the little streams adjacent to it began to be endangered. It must eventually happen that capture would become more and more imminent, or perhaps actually be accomplished. In this manner the Huron cut its way into the valley of Oak Run and beheaded it, being helped the sooner to this climax by a turn in Oak Run just opposite the point where the Huron has meandered so strongly.

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THE DEPOSITION OF THE CARBONIFEROUS FORMATIONS OF THE NORTH SLOPE OF THE OZARK UPLIFT.[1]

INTRODUCTION.

THE following study is the outgrowth of field-work performed by A. F. Smith[2] and the writer in the spring of 1902 for the Missouri Bureau of Mines and Geology. Miller county was carefully mapped,

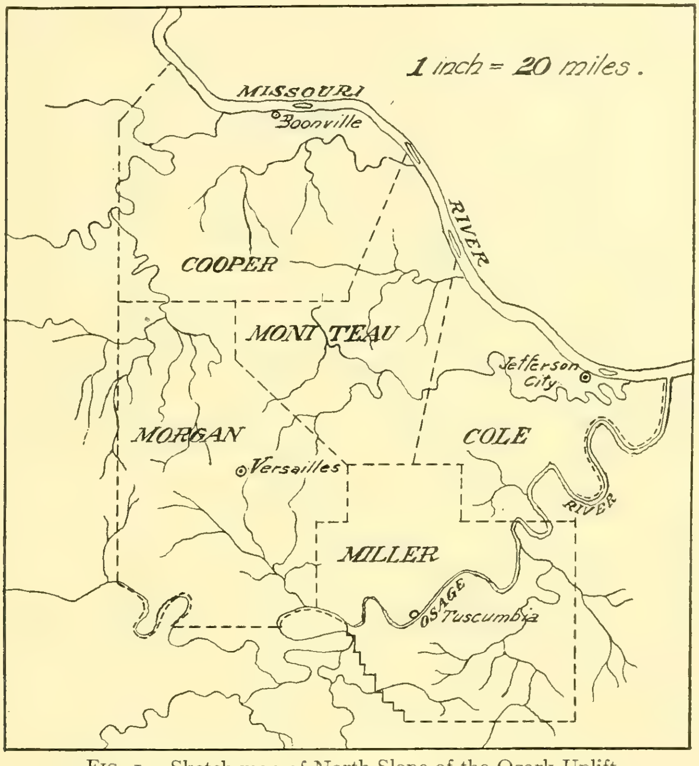

FIG. 1.—Sketch map of North Slope of the Ozark Uplift.

while Morgan, Moniteau, Cole, and Cooper counties were visited. These counties form the center of the north slope of the Ozarks. (See Fig. 1.)

[1] Published by permission of the Director of the Missouri Bureau of Mines and Geology.

[2] Acknowledgments are due A. F. Smith for valuable suggestions.

TOPOGRAPHY.

The northern flank of the Ozark uplift is a plain sloping gently to the north. Its level surface is due to Tertiary peneplanation.[1] In the vicinity of the major streams the plain is intimately dissected and the topography is mature.

STRATIGRAPHY.

The stratigraphy is summarized in the following table:

Recent.	Osage alluvium.	
Pleistocene.	Glacial bowlders in Osage alluvium.	
	Unconformity.	
Pennsylvanian	Graydon sandstone. Massive, medium-grained sandstone, more or less conglomeratic. Lithologically scarcely to be distinguished from the Pacific sandstone. 0–75 feet thick.	
	Coal-Measure shale. Shale, more or less conglomeratic, bituminous and cannel coal and limestone. 0–156 feet thick.	
	Saline Creek cave-conglomerate. Unassorted conglomerate composed of arenaceous or calcareous shale containing pebbles and blocks of older formations. Grades into Coal-Measure shale. 0–60 feet thick.	
	Unconformity.	
Mississippian	Burlington limestone. White, coarse-grained, fossiliferous limestone. 0–108 feet thick.	
	Chouteau limestone. Buff, argillaceous limestone. 0–85 feet thick.	
	Unconformity.	
Undifferentiated Cambro-Ordovician	Pacific sandstone.	Dolomites, sandstones, and shales. Referred to below as "Cambro-Silurian."
	Jefferson City formation.	
	St. Elizabeth formation.	
	Gasconade limestone.	
	Gunter sandstone.	
	Unconformity.	
Probable Cambrian	Proctor limestone.	

It is the purpose here to describe the sequence of events connected with the deposition of the Carboniferous, and particularly the Pennsylvanian, formations, rather than the detailed stratigraphy.[2]

[1] MARBUT, *Missouri Geological Survey*, Vol. X, p. 27.

[2] For stratigraphy see BALL AND SMITH, "The Geology of Miller Co.," *Missouri Geological Survey*, 2d ser., Vol. I, pp. 23–122.

THE DEPOSITION OF THE CARBONIFEROUS FORMATIONS.

The Chouteau and Burlington.—The Chouteau and the Burlington limestones lie unconformably upon the Cambro-Silurian dolomites, the Burlington apparently overlapping the Chouteau. The pre-Burlington land surface was of the same order of ruggedness as the present, and the sea advanced over the land too rapidly to cut it into a submarine plain. North of the Osage River Burlington outliers occur both on the hilltops and in the valley below. South of the Osage the present land surface is lower than the Burlington sea bottom, and only residual Burlington bowlders are now found there. Since this old topography was not base-leveled, several uplifts may have occurred between the Trenton and Burlington.

Residual Burlington chert indicates that the early Carboniferous sea covered all Missouri but the country surrounding the St. Francois Mountains. If land existed around them, it must have been incapable of furnishing large amounts of clastic material to the sea. Fossils show that the sea was teeming with animals too fragile to resist heavy waves, but requiring gentle currents to furnish food material.

The interval between the Burlington and Coal-Measure deposition.—Elevation, with contemporaneous erosion, produced, by the time of deposition of the Coal-Measure rocks, a topography similar in ruggedness to the present topography. The thickness of the Burlington limestone appears to have varied from 40 to 180 feet.

At the beginning of the elevation the rivers had renewed strength, but until the Burlington limestone, which is lacking in clastic grains, was cut through, erosive tools were doubtless lacking. Still solution occurred on a large scale, as shown by the deposition of the Saline Creek cave-conglomerate and the Coal-Measure shale in joints, enlarged by solution, in sinks and in caves. The inter-Carboniferous conditions were doubtless somewhat akin to those now existing in limestone regions in the tropics, in which we know caves and sinks to be very abundant. The extent to which observation shows solution occurred warrants a somewhat full discussion of the principles of solution.

The conditions favoring solution[1] are:

[1] The rest of this section is the application to a particular area of principles set forth in VAN HISE'S forthcoming treatise on *Metamorphism.*

1. *High carbon-dioxide content.*—The limestone deposition of the Mississippian period, as Chamberlin has shown, set free a large amount of carbon dioxide. This carbon dioxide acted as a blanket to keep in the sun's heat, and greatly increased the power of water to dissolve limestone.

2. *High barometric pressure.*—Carbon dioxide being over one and one-half times as heavy as air, its presence would increase the barometric pressure, thus proportionately increasing the chemical activity of gases and liquids.

3. *High and constant temperature.*—In post-Burlington times the Ozark region was an island about 160–200 miles in diameter. Because of its insular position and the high carbon-dioxide content in the atmosphere, the climate must have been humid, equable, and warm. The plants of the Coal-Measure shale indicate a tropical or subropical climate. The chemical activity of water at 0° C. is almost nil, but with increase in temperature the solvent power increases out of all proportion to the thermal rise. Since seasonal changes were doubtless slight, solution could work the year around.

4. *High humidity.*—The seas surrounding the Ozark island would furnish abundant moisture both to abstract the carbon dioxide from the air and to bear it through the rocks.

5. *Soluble material to act on.*—The purity of Burlington limestone and the porosity of the Cambro-Silurian dolomites render each easily soluble, and caves, sinks, and natural bridges are common in the Ozark region today. As the Burlington limestone is coarse and the Cambro-Silurian dolomites medium-grained, the relative solubility of the latter would be increased. As an illustration of this the crinoids, the largest calcite grains in the Burlington limestone, are the last to be silicified in the metamorphism to chert.

6. *Moderate topographic relief.*—Moderate topographic relief furnishes conditions favorable to slow percolation and unfavorable to excessive mechanical erosion. The presence of post-Burlington sink-holes on the upland and in the adjacent valleys indicates that the level of post-Burlington ground water, and in consequence the topography, was broadly similar to that of the present day.

7. *Thick mantle rock.*—Thick mantle rock tends to retard runoff and to increase the time in which solvent waters may act. Solu-

tion doubtless formed a deep residual soil, partially from the insoluble residue of the Burlington limestone, but largely from that of the Cambro-Silurian dolomites and sandstones.

8. *Abundant plant and animal life.*—Plants and animals are important, in producing, directly or indirectly, carbon dioxide. The tropical or subtropical climate, the humidity, and the abundant carbon dioxide favored abundant plant life.

The chief underground circulation must have been to the north and northwest to the Coal-Measure sea, following the present and doubtless the former dip of the strata. Judging from the pre-Coal-Measure sink-holes, the water level must have been from 40 to 125 feet below the pre-Coal-Measure surface. The surface circulation was probably bounded below by the intercalated shales of the Cambro-Silurian formations. At the beginning of pre-Coal-Measure erosion the surface circulation may have been but 150–250 feet deep.

Because of the ready solubility of the Burlington limestone and, perhaps, of initial depressions in the upper surface of this formation along pre-Burlington drainage lines, arising from the unequal thickness of the Burlington cover, erosion tended to exhume the old valleys. They may be referred to as "resurrected valleys"—a term kindred to "resurrected mountains" (Davis).

Deposition of the Saline Creek cave-conglomerate.—The oldest formation of the Pennsylvanian, the Saline Creek cave-conglomerate, lies in joints, enlarged by solution, in sink-holes, and in cave-galleries in the Burlington and Cambro-Silurian limestones and dolomites. At the exposure on Tavern Creek the formation is at least 60 feet deep and includes blocks 18 feet long. The Cambro-Silurian limestone dips toward the sink for 150 feet on either side. A cistern at Mr. Ramsey's follows a joint filled with Saline Creek cave-conglomerate 18 feet into a filled cave-gallery 11 feet across. The bowlders of the Saline Creek cave-conglomerate are noticeably local in origin, and are not only too large to have been transported by any streams possible with the supposed topography, but many of them are of such soft material that they could not have been carried far. The composition of the shales corresponds in a general way in lime and sand content with that of the surrounding rocks.

In consequence, it is inferred that these solution cavities were

filled partially by an in-washing of the surrounding soils, and partially by the caving-in of walls of the sink-holes and caves due to sapping by differential solution.

The unconformity between the Mississippian and Pennsylvanian is widespread throughout Missouri.[1] On the north slope of the Ozarks the unconformity is shown by (1) basal conglomerates, (2) discordance of bedding, and (3) general field relations, the Saline Creek cave-conglomerate being deposited on both the Burlington limestone and the Cambro-Silurian formations.

Deposition of the Coal-Measure shales.—The deposition of the Saline Creek cave-conglomerate continued until the region subsided practically to sea-level. Then began the deposition of the Coal-Measure shales. Clay washed into those depressions not filled by the Saline Creek cave-conglomerate. At times muck with a small clastic content was deposited, later to consolidate into cannel coal. The sink-holes clogged up with clay became fit sites for swamps. Coal beds 30–40 feet thick resulted (McClure Prospect 32 feet, Knowall 35 feet). Locally the sea encroached on the land, and argillaceous, fossiliferous limestones were deposited. That the basins of deposition were very local is shown by the dissimilarity of the rocks of neighboring Coal-Measure basins and the impossibility of correlating individual strata.

At the Republic Mine the following is a section from the underlying Jefferson City (Cambro-Silurian) formation up:

28 feet bituminous coal and shale interlaminated.

10 feet argillaceous limestone, fossiliferous { *Productus semireticulatus.* *Productus cora.* *Spirifer cameratus.* *Spirifer rockymontanus.* }

4 feet more or less calcareous shale.

4 feet variegated chert, fossiliferous.

At the William Shelton Prospect, three miles away, the succession up from the same formation is:

50 feet shale, grading into

40 feet cannel coal.

Many equally striking cases might be cited.

[1] *Missouri Geological Survey*, Vol. VII, p. 438.

The Coal-Measure shales were deposited in sinks, enlarged joints, and cave-galleries—a fact indicated by their small area and relatively great depth. The Knowall Prospect penetrated 85 feet of Coal-Measure shale. Four drill-holes in the immediate vicinity penetrated only the Cambro-Silurian dolomites. A shaft in the Gageville Mine passed through 50 feet of Cambro-Silurian dolomite and then 10 feet of Coal-Measure shale, the contact being very irregular (Fig. 2). This appears to be a cave-gallery, and may con-

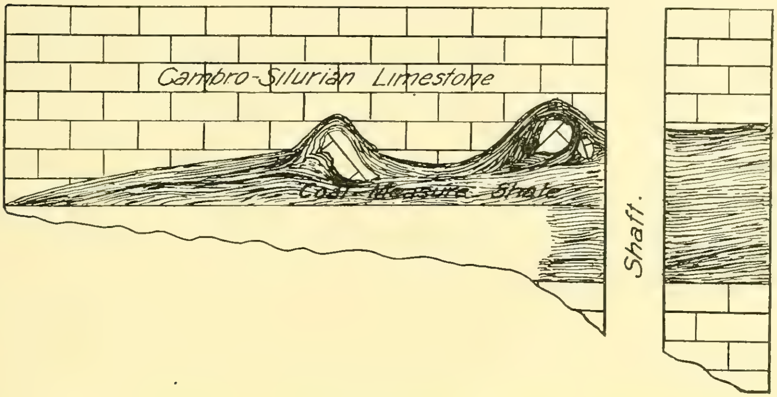

FIG. 2.—Cave-gallery filled with Coal-Measure Shale, Gageville Mine.

nect with another shale outcrop in the valley below. Coal-Measure shale occurs in a pocket 50 feet in diameter in a valley at the Son Prospect. On the hillside a shaft passed through $4\frac{1}{2}$ feet of Cambro-Silurian dolomite into the shale (Fig. 3). Further evidence is the fact that the Cambro-Silurian dolomites dip, as a rule, toward the shale outcrops, often as much as 30°.

Deposition of the Graydon sandstone.—The exact time-relations between the Coal-Measure shale and the Graydon sandstone is as yet not certain, but the weight of evidence seems to make the Graydon sandstone the younger. However, the two may have been contemporaneously deposited in various parts of the country, or the sandstone may have been deposited at two or more times.

The Graydon sandstone exposures rest on the Burlington limestone and on the Cambro-Silurian formations. In the little dissected plain it occurs in many small round areas; in the more dissected

regions the exposures are fewer, possess a trail-like form, and are largely confined to valleys. From the latter conditions we infer that in the vicinity of the river, erosion has removed all but the Graydon sandstone deposited in deep gulches. These again seem "resurrected" valleys. The inclosing Cambro-Silurian walls are undisturbed, and seem to delimit normal erosion valleys.

The Graydon sandstone appears to have been deposited upon a surface somewhat like the present, with the greatest dissection in the vicinity of the Osage River. If important valleys of Graydon age had existed in the upland, we should find in this little dissected

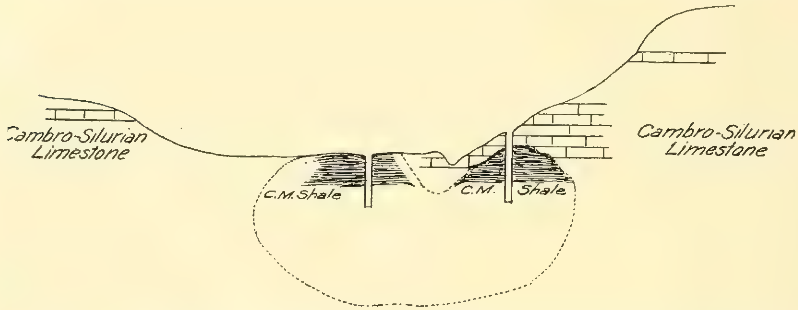

FIG. 3.—Cross-section—Son Prospect. Dotted line shows hypothetical extent of Coal-Measure shale.

portion of the uplift sandstone outcrops corresponding to them. If in the vicinity of the Osage the streams had run counter to the present channels, we would expect the resistant Cambro-Silurian rocks to preserve more filled channels crossing the present divides.

Cross-bedding and pebbles occur throughout the sandstone, and so deposition apparently kept pace with gradual depression. The first beds were perhaps deposited in estuaries, while later the whole land may have been submerged. From the probable geography of the time it may be suggested that the sand came from the south or southeast. From its lack of felspathic material, it was doubtless derived from the older Cambro-Silurian sandstones, and not from the granites of southeast Missouri.

After the deposition of the Graydon sandstone the land was again uplifted.

RÉSUMÉ.

On the north slope of the Ozark uplift the Burlington (in places the Chouteau) limestone rests unconformably upon the Cambro-Silurian formations, and the Pennsylvanian formations, in turn, rest unconformably upon the Burlington limestone and the Cambro-Silurian rocks. During the late Mississippian period, solution was unusually active, and the Saline Creek cave-conglomerate and Coal-Measure shale lie largely in solution cavities, developed previous to their deposition. The Graydon sandstone, when it rests on Cambro-Silurian rock, occupies normal erosion valleys. The present position and extent of the Carboniferous deposits is determined by several factors, among which the pre-Carboniferous and inter-Carboniferous land surfaces and post-Carboniferous erosion are important.

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ECLOGITES IN CALIFORNIA.[1]

CONTENTS.

THE term "eclogite" was first introduced into the geological literature of Europe in 1822 by Haüy in his *Traité de mineralogie*, in which he gave the name to a rock composed chiefly of green augite and garnets. In the present paper the name is applied to a rock derived from some eruptive and bearing garnets in a matrix composed essentially of some form of augite, or of hornblende, or of both augite and hornblende. The various secondary minerals are given in the descriptions that follow. The term eclogite has proved useful, and the rock has evidently been an interesting one to European petrographers, for as far back as 1884 Lohmann[2] gives two pages of bibliography as an introduction to his paper on eclogites. Since then many articles have appeared in English and continental journals, the most recent being the excellent paper by Hezner,[3] which gives a discussion of the petrographical relations of eclogites and amphibolites found in the Tyrol Alps, with a bibliography of over seventy references. Hezner's article was received after the present paper was written, and although some few extracts from it have been inserted, the special student of these rocks is referred to the original article for the full details of this important contribution to the subject.

[1] The writer is under obligations to Dr. J. P. Smith, of Stanford University, for suggestions and advice.

[2] "Neue Beiträge zur Kenntniss des Eklogits vom mikroskopischen, mineralogischen und archäologischen Standpunkt," *Neues Jahrbuch für Mineralogie, Geologie und Paleontologie*, Vol. I (1884).

[3] "Ein Beitrag zur Kenntnis der Eklogite und Amphibolite," Tschermak. Mineralogisch-petrographische *Mitteilungen*, Vol. XXII (1903).

Hitherto, so far as known to the writer, no rocks have been described in the country under the title of eclogites. Nutter and Barber[1] refer to them incidentally in their discussion of glaucophane schists, and Diller[2] has recently included some rocks of the eclogite type in his description of the amphibole schists of Port Orford, Ore., but without designating them by this term. A brief preliminary review of the eclogites of Europe will furnish a basis for comparison in the study of those of our west coast.

EUROPEAN ECLOGITES.

The type eclogite of Europe is described in the valuable paper of Lüdecke,[3] who gives a detailed account of the chief minerals and of a dozen rocks found in the island of Syra. Of these latter he places glaucophane eclogite as the most important. This consists of red garnets, light green omphacite, and glaucophane. He mentions muscovite, quartz, and pyrite as accessory minerals. The omphacite is a light green augite appearing in grains and in small columns, sometimes showing the augite cleavage. Under the microscope there is little or no pleochroism, bright polarization, and a high extinction angle. The garnets are rhombic dodecahedrons with rounded corners. The glaucophane is the same as that so common on the Pacific coast, and which will be described more fully later. The garnet is considered the oldest mineral; younger than that is placed glaucophane and omphacite; and youngest of all, the quartz. In the laboratory at Stanford University are small specimens of the Syra eclogite—obtained through the kindness of Mr. Diller—which very much resemble some facies of the glaucophane eclogite of Tiburon. The glaucophane is a trifle darker blue, and the garnets do not show such definite crystal forms as do those in the California rock. In his general description of eclogites Lohmann reports the occurrence of the rock in Norway, Switzerland, Austria, France, Italy, Greece, and South Africa. Lohmann's paper is mainly devoted to an account

[1] "On Some Glaucophane and Associated Schists," JOURNAL OF GEOLOGY, Vol. X, p. 738.

[2] Folio No. 89, *Geological Atlas of the United States.*

[3] "Der Glaucophane und die glaucophane-führende Gesteine der Insel Syra," *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. XXVII (1876).

of the stone axes made from eclogites, but his bibliography and his summaries of previous geological descriptions are of great value to the petrographer. Teall[1] describes an eclogite from the British Isles. This rock has a dull green color with reddish-brown garnets. The groundmass is omphacite with intergrowths of hornblende, feldspar, and rutile—rarely with quartz and epidote. The hornblende is strongly pleochroic. The color of the $\mathfrak{c}$ ray is bluish-green; $\mathfrak{b}$, deep rich green; $\mathfrak{a}$, pale yellowish-brown. Bonney,[2] under a subheading of igneous rocks, describes a massive hornblende rock that appears to be a diorite and contains many small garnets with sphene, quartz, plagioclase, and zircon as probable accessories. He concludes that the rock might be termed a hornblende eclogite.

Patton[3] describes a "Kelyphite eclogite" from Bohemia in which the garnets are surrounded by a ring or mantle usually of hornblende and feldspar. The groundmass is a complex of hornblende and pyroxene crystals. Another outcrop with striated feldspar in the groundmass he calls, not eclogite, but an eclogite-like rock. With the disappearance of the omphacite and garnets and of the kelyphite ring the structure becomes more schistose and the rock passes into ordinary hornblende schist.

The eclogites of Bavaria are described by Newland[4] as forming a series of hills extending for some fifteen miles in the Bavarian mountains. He finds that the eclogite grades over into a basic gneiss of hornblende, garnets, and feldspar, but not into the more acid gneiss. The eclogite consists essentially of omphacite, hornblende, and garnets, with the usual accessory minerals. The analyses which he gives of Bavarian eclogites are quoted later.

Traube[5] describes an eclogite in Silesia occurring with gabbro, amphibole, and serpentine, and forming bands separated by serpen-

[1] "On an Ecolgite from Loch Duich," *Mineralogical Magazine*, Vol. IX, p. 217.

[2] "Notes on the Vicinity of the Upper Part of Loch Maree," *Quarterly Journal of the Geological Society*, Vol. XXXVI (1880), p. 105.

[3] "Die Serpentin-und Amphibole-Gesteine nördlich von Marienbad in Böhmen," *Tscherm. min.-petr. Mitth.*, Vol. IX (1887), p. 89.

[4] "Notes on the Eclogite of the Bavarian Fichtel-Gebirge," *Transactions of the New York Academy of Science*, Vol. XVI, p. 24.

[5] "Ueber ein Vorkommen von Eklogite in Schlesien," *Neues Jahrbuch*, Vol. I (1889), p. 195.

tine. The eclogite from the Tyrol Alps recently described by Hezner[1] is composed primarily of clear red garnets, commonly in rounded grains, in a groundmass of emerald-green omphacite. The garnets vary from fine grains up to the size of peas, but the crystal form is seldom distinct. Hezner considers that this eclogite is chemically a gabbro or a variation of the same magma that furnished the gabbro. Eclogite, he thinks, is formed in the greatest depths and in the higher zones amphibolite—the garnet and the omphacite being amphibolized.

The foregoing brief extracts will give some idea of the eclogites of Europe and of their probable derivation.

CALIFORNIA ECLOGITES.

Probably the most typical eclogite in California is that found in the bed of Coyote Creek, about eighteen miles southeast of San José and some six miles east of north from San Martin. The outcrop of massive rock is exposed for about twenty feet in the edge of the stream. Apparently it breaks through the shale and jasper exposed at the foot of the hill only a few feet away, but the gravel of the creek entirely covers the contact. On the opposite side of the stream, and within a hundred yards, is a large mass of serpentine, which, however, is not in contact with the eclogite. The most characteristic facies of the outcrop is that which shows a grass-green groundmass, thickly studded with dark red garnets several millimeters in diameter and showing distinctly the rhombic dodecahedron form. The faces of the garnet are fresh and shining, with clear-cut edges. The reproduction of the photograph in Fig. 1 shows the structure of the rock, but the striking effect of the red garnets in the light green groundmass is unfortunately lost.

Seams and segregations of glaucophane, sometimes bearing garnets, occur in the exposure. Prominent veins of a fine-grained reddish mineral were taken in the field for inclusions of the nearby jasper, but its fusibility, and its isotropic character under the microscope, proved it to be a compact variety of garnet. Segregations of actinolite crystals are common, and chlorite frequently occurs. Some particles of chalcopyrite are seen in the rock, and a few parti-

[1] *Op. ci .*

cles of free gold were found in the granular garnet. The rock has attracted the attention of prospectors, and it is reported that an assay showed nearly two dollars of gold per ton. In a few places there were inclusions, some 10–15^{mm} in diameter, of a reddish-brown mineral with cleavage faces giving an almost metallic luster. In the laboratory the mineral was found to be infusible and to possess a hardness

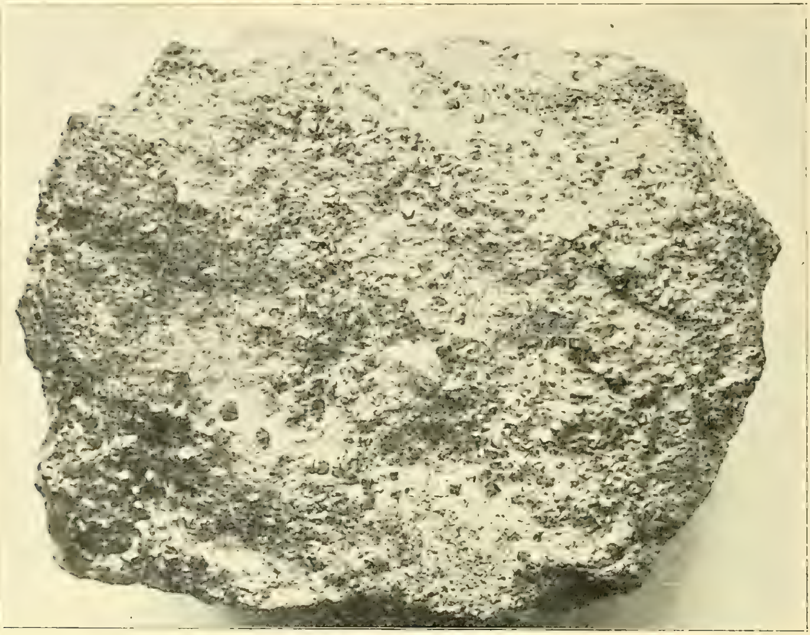

FIG. 1.—Eclogite from San Martin, Calif. Slightly reduced in size.

of over six. The streak is yellowish-brown. A determination of the specific gravity of the purest fragment obtainable gave a result of 4.154. After fusion with soda the acid solution boiled with tin gives the violet reaction of titanium. The mineral was determined as rutile—a result which the microscopic examination of a thin section confirmed.

The specific gravity of the eclogite itself varied from 3.33 to 3.58 in different fragments—apparently varying with the number of garnets included. Some of the garnets were separated from the groundmass and found to have a specific gravity of 3.68. A qualitative determi-

nation of the garnets indicates that they are the iron-alumina variety with a considerable amount of calcium.

Under the microscope the main groundmass of the eclogite is seen to be light-green omphacite, with little, if any, pleochroism. The interference colors are bright, and the extinction angle runs up to 40°. The garnets show regular outlines, and are of a pale pink color by transmitted light. Usually they are cracked, with omphacite filling the cracks. Rutile is present as a segregation in the groundmass and as inclusions in the garnets. Sphene of a light brownish color, somewhat pleochroic, and with characteristic relief, is plentifully distributed in irregular grains.

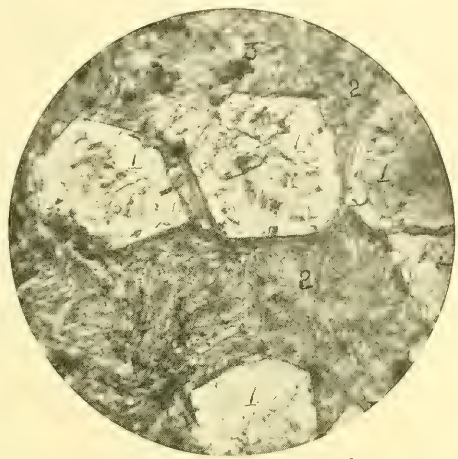

FIG. 2.—Omphacite eclogite, San Martin. × 24. 1 = garnet, 2 = omphacite, 3 = rutile.

The microphotograph in Fig. 2 shows the clear outlines of the garnets. The inclusions in them are omphacite, apatite, rutile, quartz, and sometimes chlorite. The felted groundmass is composed of small columns of omphacite. Many of the slides are practically free from glaucophane, although veins of this mineral are quite plentiful in the exposure. The glaucophane is a somewhat more definite blue than is usually described as steel-blue, and in the slide shows strong pleochroism. The color of the $\mathfrak{a}$ ray is a very pale yellow; the $\mathfrak{b}$ ray, a purplish violet; the $\mathfrak{c}$ ray, a clear blue. The extinction angles in several sections were found to be close to 5°. The orientation is that common in glaucophane, with the $\mathfrak{b}$ axis corresponding to the axis of symmetry and the $\mathfrak{c}$ axis nearest to c'. In places the glaucophane grades over into a green hornblende. In one of the slides there is an irregular-shaped mineral of a light brown color and cut by intersecting cracks. It is pleochroic in tints of brown. The relief is high, and the interference colors are of the third or fourth

order. While this mineral differs somewhat from the sphene appearing in grains, it is thought to be the same, although possibly somewhat changed by decomposition.

Calaveras Valley.—This little valley is in Santa Clara county, about fifteen miles northwest from the Lick Observatory. In it are found two distinct kinds of eclogite—a light-green omphacite variety and a dark, almost black, hornblende eclogite. The first occurs at the mouth of the narrow gorge which is the outlet of the valley to the north. The outcrop is on the west side of the stream on the bank of the flood-plain, and is about a hundred feet long. On the hillside above, serpentine is found, and in the stream-bed below, shale and sandstone, with characteristic Miocene fossils.

The dark hornblende eclogite is farther upstream on the east side of the valley. The exposure is over a hundred feet in thickness, and was followed southward for more than a half-mile without finding the limit. On the upper side is a greenstone with an extensive serpentine belt lying just above. Farther upstream sandstone occurs between the eclogite and the serpentine. The eclogite appears to be a dike cutting across the Franciscan sandstone.

The green eclogite of the lower exposure varies considerably in its appearance. The garnets are sometimes small and clear-cut, sometimes 8 to 10^{mm} in diameter and without definite form. Glaucophane is also very irregularly distributed throughout the exposure. Under the microscope the groundmass is seen to be largely composed of closely packed little columns of omphacite. Much of it shows wavy extinction, as if the rock had been subjected to crushing. This is also indicated by the badly fractured condition of the larger garnets. Part of the green groundmass is probably the grass-green hornblende, smaragdite, although rather indefinite results were obtained in measuring extinction angles. Irregular light-colored sphene granules are scattered freely through the slides. A mineral with lighter color than the omphacite shows some pleochroism and very low interference colors. It was determined as chlorite, and is probably derived from the hornblende or the augite. In places it shows a bright Prussian blue interference color—according to Rosenbusch, a characteristic of the pennine division of chlorites. Glaucophane is plentiful in some of the slides and in a few instances gave an

extinction angle as high as 15° for the angle of c on c'. Small quantities of feldspar and quartz appear in some of the slides.

The relations of the glaucophane and the chlorite are interesting, as seen in Fig. 3, where the two minerals are apparently reacting in some way. Along the line of contact there is a deep blue border as indicated in the sketch. In Fig. 4, which is from the same slide, the crystal of glaucophane cuts clearly through the chlorite. The latter has evidently been sheared by some stress, and the glaucophane is a later growth. The chlorite crystal has a definite extinction angle of

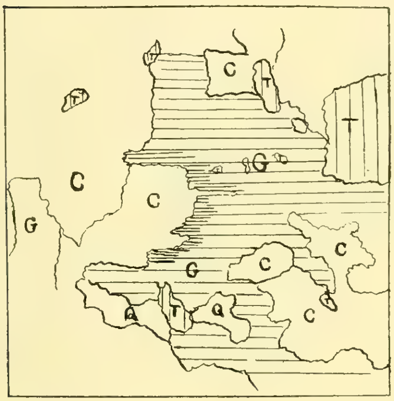

FIG. 3.

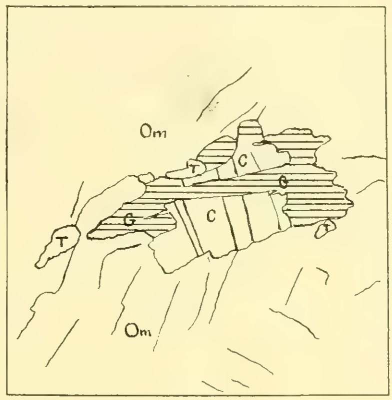

FIG. 4.

G = glaucophane, *C* = chlorite, *T* = sphene, *Q* = quartz, *Om* = omphacite

15°, which may indicate formation from hornblende, for the chlorite properly has small extinction angles or no definite extinction.

The dark hornblende eclogite in Calaveras Valley is the only one of its kind yet found in the state. Macroscopically it shows the dark hornblende with fresh cleavage faces, and with garnets plentiful in some specimens and few in others. Before the blowpipe the hornblende melts easily to a magnetic globule, at the same time coloring the flame yellow.

In the slide nearly all possible sections of the hornblende are found, as may be seen in the accompanying microphotograph. The garnets lack the clear outlines so noticeable in the San Martin eclogite. Some of the hornblende crystals are bordered with glaucophane, which appears white in the photograph. The hornblende

is strongly pleochroic as follows: **a**, light greenish-yellow; **b**, olive-green; **c**, greenish-blue. The orientation is the same as in glaucophane the **b** axis corresponding to the axis of symmetry and the extinction angle of **c** on *c′* is nearly 25°. This angle is unusually large for hornblende. Hintze,[1] however, gives some still greater. His table of extinction angles for hornblende varies from 16° to 27° 30′, the percentage of Al_2O_3 varying at the same time from 1.89 to 20.73. A black hornblende, pargasite, has an extinction angle, **c** on *c′*, of 24° 30′ the Al_2O_3 varying from 11.92 to 13.75 per cent. A light green pargasite is given with a slightly higher extinction angle, and also a higher percentage of alumina. The pleochroism is not given in the same table, but a few pages later he gives the following for a light pargasite: **a**, g eenish-yellow; **b**, emerald-green; **c**, greenish-blue. It should be noted that pargasite is sometimes blue and appears to be usually soda-bearing, as the analyses quoted by Hintze show.

FIG. 5.— Hornblende eclogite, Calaveras. × 24. 1 = garnet, 2 = quartz, 3 = hornblende, 4 = rutile, 5 = glaucophane.

Blasdale[2] describes a hornblende from the vicinity of Berkeley with a pleochroism of **c**, bluish-green; **b**, yellowish-green; **a**, lighter green. The extinction angle is given as 14° 34′, and the percentage of soda 2.45 and of alumina 2.05–3.45. The glaucophane in the Calaveras hornblende eclogite is along the borders of the hornblende crystals, and is apparently of a later growth. A similar instance of such a change is described by Cross,[3] who found blue hornblende upon the ends of a brown hornblende occurring near Silver Cliff, Colo.

[1] *Handbuch der Mineralogie,* Vol. II, p. 1188.

[2] "Contributions to Mineralogy," *Bulletin of the Department of Geology, University of California,* Vol. II, p. 328.

[3] "Some Secondary Minerals of the Amphibole and Pyroxene Groups," *American Journal of Science,* Vol. XXXIX (1890), p. 359.

The garnets in the hornblende eclogite have a fresh, clear color, and show little sign of change, but they are much cracked. Small quantities of feldspar and of quartz are found in the different slides. An opaque irregular mass shows by reflected light a yellow center and a black border. It is undoubtedly pyrite surrounded by iron oxide.

A hand specimen of eclogite has recently been sent to the writer by W. D. Smith, who collected it at a point some four miles south of east from the Calaveras exposure described in this paper. It carries coarse red garnets up to a half-inch in diameter, some of them showing well the rhombic dodecahedral form. The groundmass seems to be chlorite, glaucophane, and omphacite. The eclogite most resembles the San Martin variety, but is not quite so fresh in appearance. No igneous rock is reported from the vicinity.

Tiburon.—In addition to the interest attached to this locality because of the discovery of lawsonite, the peninsula of Tiburon in San Francisco Bay is noteworthy from the number of outcrops of eclogite found there. Much of the rocky knoll near Reed Station, where the lawsonite occurs, is eclogite of the glaucophane-omphacite variety. The minerals in this rock have been described by Ransome.[1] On the top of the hill above the lawsonite are two outcrops of eclogite occurring in the serpentine area. These have more omphacite than glaucophane, while on the slope of the hill beyond a glaucophane eclogite occurs that is almost free from omphacite. The slides from the first outcrop were mainly selected to show lawsonite, and so the proportion of that mineral appears unduly large. The matrix is usually composed of small allotromorphic crystals of a grass-green color intergrown with glaucophane. The green mineral shows no pleochroism in most cases. The extinction is frequently wavy, but where it admits of measurement the maximum angle is close to 40°. The mineral is identified as omphacite, with a probability that a portion of the green matrix is hornblende. In some cases the garnets are almost entirely replaced by chlorite; in others there is a celyphite border of the chlorite. In one instance the garnet has a celyphite border of mica. Mica is very common in these slides, and is determined as margasite by Ransome, to whom reference is made for the full description of the associated minerals.

[1] "On Lawsonite, a New Rock-Forming Mineral," *Bulletin of the Department of Geology, University of California*, Vol. I, p. 311.

San José.—The hills just south of the Oak Hill Cemetery are composed largely of masses of peridotite and gabbro with the resulting serpentine. On one slope there is an outcrop of grayish-green rock that is in part eclogite. The garnets are small and sometimes form veins of the compact granular variety of this mineral. In the slide there is much glaucophane and chlorite, the latter frequently exhibiting the Prussian blue interference color. A few crystals of feldspar are found, and also considerable mica and sphene. The outcrop is of interest mainly because of its occurrence in an area of igneous rocks.

Eclogites from other localities.—Slides and hand specimens from Sonoma county have been studied in the laboratory. They are of the glaucophane type of eclogite and have the usual accessories. Nutter and Barber[1] state that the eclogite occurs in large masses associated with schists. Melville[2] describes a bluish glaucophane schist from Mount Diablo with streaks of green and with innumerable garnets. No slide or hand specimen has been available. Among the rocks of Catalina Island, W. S. T. Smith[3] describes a garnet amphibole of greenish or brownish hornblende and carrying roughly rounded garnets. Rutile is mentioned as an inclusion. The term "eclogite" is not used in his account. A specimen of eclogite from Anacapa Island, some sixty miles to the northwest of Catalina, is in the Law collection, but there is no note as to its occurrence.

OREGON ECLOGITE.

Although the locality is outside of California, fuller reference should be made to the rocks described by Diller from Port Orford. He finds glaucophane-, actinolite-, mica-, and epidote-schists all grading into each other and all having the same origin. Garnets are sometimes found in abundance. These schists he thinks are derived from rocks of the basaltic type. In many places the original rock is changed to plagioclase hornblende rock. Usually the pyroxene alters to a green hornblende, but sometimes to a blue—giving the

[1] *Op. cit.*, p. 740.

[2] "Notes on the Chemistry of the Mount Diablo Rocks," *Bulletin of the Geological Society of America*, Vol. II, p. 403.

[3] "The Geology of Catalina Island," *Proceedings of the California Academy of Science*, Geology, 3d ser., Vol. I, p. 62.

glaucophane schist. While the alteration is generally complete, he found a volcanic neck where on one side the change is not entire, and under the microscope augite is seen changing into glaucophane. The feldspar has changed chiefly to epidote. Some green hornblende and chlorite are present. An examination of several slides—kindly loaned by Mr. Diller to Dr. J. P. Smith—shows that part of them may be classed as glaucophane eclogites. One specimen from Winston's Bridge is essentially glaucophane and garnets—the latter 2–3^{mm} in diameter. Mica, chlorite, sphene, and epidote are also present. An analysis of this rock without the garnets, as given by Washington,[1] is included in the table herewith.

CONCLUSION.

The question of the derivation of eclogites and of their place in the series of metamorphic rocks is both interesting and difficult. In the absence of direct proof for any special instance at hand opinions as to the igneous origin of a metamorphic rock should be given with due reservation. It seems to be well established that both igneous and sedimentary rocks sometimes grade into schistose forms that appear to be indistinguishable on first examination. From the evidence now at hand the writer would conclude that the San Martin and the Calaveras eclogites are derived from basic eruptives of the gabbro type. This derivation is indicated by their massive and irregular appearance in the field as well as by the general field relations.

The occurrence of the San José eclogite in the Oak Hill area of igneous rocks indicates that we have there merely the modification of a rock derived from the same magma as the basic eruptives that form the hills. The igneous origin of the San Martin eclogite is also indicated by the chemical analysis. As may be seen in the accompanying table, the silica is only slightly over 44 per cent.—which indicates derivation from some very basic eruptive. The percentage of silica is very close to that given by Hezner in the two analyses which he has made. Hezner thinks that his analyses show well the normal chemical composition of eclogites. The table of analyses here given should be supplemented by additional work on the California eclogites, but it is at least suggestive in the comparisons which it affords.

[1] "Study of the Glaucophane Schists," *American Journal of Science*, Vol. CLXI.

ANALYSES OF EGLOGITES AND RELATED ROCKS.

	1	2	3	4	5	6	7	8	9
SiO_2	44.15	44.06	46.26	57.10	55.00	48.81	46.07	46.88	41.20
Al_2O_3	10.18	17.63	14.45	11.66	13.54	16.25	15.35	19.16	15.40
Fe_2O_3	11.92	3.40	4.41	2.84	2.74	6.00	3.61	10.63	2.49
FeO	13.04	9.96	5.82	3.22	3.37	7.48	9.87		4.67
MgO	6.18	7.19	11.94	6.37	10.21	7.12	7.83	9.48	15.51
CaO	4.51	11.58	11.66	13.80	12.09	9.72	4.37	13.37	12.26
Na_2O	5.11	2.92	2.45	2.21	2.10	2.64	3.22	......	3.44
K_2O	2.09	0.91	1.51	0.81	0.50	0.46	2.68	......	2.49
H_2O +110°	0.95	0.17	......	0.54	0.32	0.12	4.25	......	1.31
H_2O −110°		0.12	1.10				0.16	......	
CO_2	......	......	......	......	......	......	1.05	......	......
TiO_2	Tr	2.29	0.28	......	......	......	1.63	0.18	0.43
MnO	......	......	......	0.31	0.20	0.43	tr.	......	Fl. 1.86
Total	99.31	100.23	99.93	98.86	100.27	99.03	100.09	99.67	......

1. San Martin eclogite, Analysis by C. B. Allen (kindness of Dr. J. P. Smith).

2 and 3. Tyrol eclogites. L. Hezner.

4, 5, and 6. Bavarian eclogites quoted, by Newlands.

7. Glaucophane (eclogite?) from Oregon. Washington.

8. Gabbro. Oak Hill, San José. Analysis furnished Dr. J. C. Branner by U. S. Geological Survey.

9. Pargasite, steel-blue to black. Hintze.

The opinions of Diller, Bonney, and Traube as to the igneous origin of certain eclogites have already been quoted. Harker[1] gives a brief description of eclogites, and quotes Fouqué and Lévy as to a French hornblende eclogite that is "a local modification of a diorite."

In connection with the igneous origin of eclogites, the writer tried the experiment of fusing several specimens in a coke assay furnace. The crucibles were kept at the highest temperature of the furnace for about three hours, and then the drafts were closed and the whole allowed to cool slowly overnight. The eclogites fused easily to homogeneous lava like obsidian. Under the microscope this showed a practically uniform isotropic character. With a high power points showing double refraction were found scattered through the slide, but no detail could be made out.

A list of the constituent minerals found in California eclogites, and a brief mention of their properties as they are found in these rocks, will unify the preceding descriptions.

First among the essential minerals is garnet. The color is usually a dark red in the hand specimen. In size the garnets vary from 2 to 5^{mm}, for the well-developed dodecahedrons of the San Martin eclogite,

[1] *Petrology for Students*, 1887, p. 329.

to 10 or 12^{mm} for the rounded forms in some of the Calaveras exposures. Of the essential minerals garnet is evidently the oldest, for in the cracks are found glaucophane, omphacite, and hornblende. Yet these latter minerals are also found as inclusions together with rutile, apatite, feldspar, and quartz. Inclusions of glaucophane may be paramorphs of inclusions in the original matrix. Qualitative tests indicate that the garnets contain iron, calcium, and aluminum.

Omphacite, the light green augite, usually occurs in aggregates of prismatic crystals, some a $\frac{1}{2}^{mm}$ in length and without definite termination. The bright polarization, absence of pleochroism, high extinction angle, and occasional augite cleavage serve to distinguish it. Lüdecke deduced the formula $(CaFe)\ SiO_3MgSiO_3$ from his chemical analyses.

Smaragdite is an emerald-green actinolite that in the eclogites much resembles omphacite, being distinguished from it by the hornblende extinction angle and usually by pleochroism. The blue soda hornblende, glaucophane, has the marked pleochroism already given and an extinction angle of $\mathfrak{c}$ on c' varying from 5 to 15°. It seems to be derived from hornblende in the eclogite in Calaveras Valley—at least the hornblende crystals are bordered by it. Diller has already been quoted as to the change of pyroxene to glaucophane in the Port Orford rocks, some of which are here classed as eclogites. The analyses of some of the igneous rocks considered show that they contain enough soda for this change to occur without the addition of elements from the outside. The hornblende in the Calaveras eclogite show soda in the qualitative test, and also has a general resemblance to glaucophane in its pleochroism and in its orientation. Hintze has already been quoted in regard to a black pargasite that seems to agree closely with the Calaveras variety of hornblende in pleochroism and extinction angle. This pargasite contains, according to his analysis, 3.44 per cent. of soda—which is more than the percentage of soda in the Port Orford glaucophane.

Both garnet and hornblende are found replaced by chlorite—pale green in color, and showing low interference colors except in the pennine variety, which shows Prussian blue between crossed nicols.

Mica seems to be absent from the Calaveras slides and is found in very small quantities in those from San Martin. In the Tiburon

eclogite margasite is very plentiful and has been fully described by Ransome, as already cited. White mica, probably paragonite, occurs in the San José eclogite and in that from Sonoma county.

Titanite, or sphene, is thickly distributed in some of the slides in very minute grains. It is a very light brown color and pleochroic in tints of that color. Rutile in large crystals 10–15^{mm} in diameter is found only at San Martin, but it is found somewhat less freely than sphene in the shape of small irregular grains in nearly all the slides. It is yellowish to reddish-brown and somewhat pleochroic, and has very high relief.

Epidote is rather irregular in its occurrence. When found, it exhibits lower interference colors than those usually described. Ransome[1] thinks that this is accounted for by a smaller proportion of iron, and that in chemical constitution the epidote may grade over into zoisite. Zoisite and cyanite were seldom found. Pyrite appears occasionally, but not so frequently as was expected from the description of the European eclogites.

All of the above minerals are possibly secondary in their occurrence in eclogites. The occasional feldspar and quartz may be the only minerals remaining unchanged from the original rock. The garnets and the epidote have probably taken up the line of the original feldspar, while the soda is to be found in the glaucophane or in the pargasite variety of hornblende.

While the use of the term "eclogite" is now fairly definite, there is still a question of some limitations in its application. In constitution the rock must contain garnets in a matrix of omphacite, glaucophane, or hornblende, or of some mixture of these minerals. Hezner evidently would insist that there must be omphacite, for even with about equal proportions of hornblende he drops the term "eclogite" and uses "eclogite-amphibolite." The common accessory minerals are sphene, rutile, cpidote, apatite, zoisite, cyanite, feldspar, and quartz. While some metamorphosed sedimentary rocks approach eclogites in composition, the tendency seems to be to restrict the term to rocks that are clearly of igneous derivation.

RULIFF S. HOLWAY.

BERKELEY, CALIF.

[1] *Op. cit*, p. 310.

Editorial.

It is always a pleasure to note a graceful expression of appreciation of long and faithful endeavor to promote our science—doubly so when this service has been given in a singularly quiet and modest way, without any apparent realization of its true merits.

At a recent alumni dinner of the State University of Iowa, the former students of Professor Samuel Calvin, to the number of over two thousand, united in the commemoration of the completion of his thirtieth year as professor in that institution. The recognition took the form of a costly silver loving-cup, designed especially for the purpose of symbolizing the scientific achievements of the recipient. The cup is a classic Greek vase, sixteen inches in height, and stands on a base of serpentine five inches high. It is adorned with casts taken directly from fossils, with a drainage map of Iowa, with crossed geological hammers, a microscope, and the more conventional spray of laurel, owl of wisdom, and torch of learning—all in relief. One side bears an appropriate inscription in raised letters.

Professor Calvin was elected to the chair of natural history in Iowa's university thirty years ago. The chair has since been subdivided into four distinct departments, Professor Calvin retaining the department of geology. As well known to the profession, he has been state geologist of Iowa during the last twelve years, and an admirable series of reports is appearing under his administration.

Reviews.

Catalogue of the Ward-Coonley Collection of Meteorites. By Henry A. Ward. Chicago, 1904.

The third catalogue of this collection has been issued within four years as a consequence of its rapid growth from 424 falls in 1900 to 603 falls in 1904. The weight of the present collection aggregates 2,495 ^{kg}. It contains 241 falls of siderites, 28 of siderolites, and 334 of aerolit s. The number of specimens is about 1600. The greater number of falls is from North America and Europe, but there are considerable numbers from Asia, Africa, Australia, Sandwich Islands, and South America.

The catalogue is prefaced by a statement of the method by which the collection was gathered together and an account of the most noteworthy specimens. Under the entry of each fall is given the date and locality of fall, the name and description of the meteorite, the reference to the published description, together with the weight of the chief piece and the total weight of the material in the collection.

There is in addition an alphabetical list of all known meteorites, and another giving their geographical distribution, arranged according to countries. This is followed by a statement of the latest revised classification of meteorites by Dr. Aristides Brezina, of Vienna, giving the system, composition, and name, with the list of meteorites belonging to each division.

The Ward-Coonley collection also contains a library of over 800 titles, besides some minerals characteristic of meteorites, a small collection of their sections, specimens of terrestrial iron, and a series of casts of meteorites. The collection is at present exhibited in the American Museum of Natural History in New York city.

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DESCRIPTION AND CORRELATION OF THE ROMNEY FORMATION OF MARYLAND.[1]

CONDENSED DESCRIPTION OF THE ROMNEY FORMATION.

THE lower member of the Romney formation in Allegany county is composed principally of fissile black shale, some of which weathers to a yellowish or buff color on long exposure. In comparatively fresh exposures, however, as in the railroad cuts at Twenty-first Bridge, the shales are either black or rusty-brown after some weathering. The black shales are shown to best advantage in these cuts, although on the Williams Road, three and one-half miles southeast of Cumberland, is perhaps the most nearly complete exposure of this division with an approximate thickness of 512 feet. In the lower part of some of these exposures are bands of very dark-colored thin limestone. The lithological characters of these shales agree closely with those of typical exposures of the Marcellus shales in New York state, and in addition they contain such characteristic species as *Liorhynchus limitare* (Vanuxem) and *Agonitaites expansus* (Vanuxem).

The second member of the Romney formation, the Hamilton beds, has an approximate thickness of 1,100 feet, and is composed of shales and sandstones. In recent exposures the shales, generally bluish or bluish-gray in color, vary in composition from quite coarse arenaceous to those that are fine and argillaceous. The sandstones,

[1] Published by permission of Dr. William Bullock Clark, state geologist of Maryland. The data upon which this paper is based will appear in detail in the forthcoming Devonian volume of the Maryland Geological Survey.

which on fresh surface are generally blue or gray in color, are not very coarse in texture, and the layers are often less than a foot thick. All of these rocks, however, on long exposure usually present along the highways a slightly greenish or yellowish-gray tint. There are two prominent sandstone zones in this member of the formation, varying in thickness from about 30 to 75 feet. The lower one is from 500 to 550 feet above the base of this division, or from 1,000 to 1,050 feet above the base of the formation, while the upper zone is at or near the top of the formation. Both of these sandstone zones are clearly shown in the sections on the Williams Road and at Great Cacapon, and the upper one at Gilpin and above Corriganville. The shales in many localities are very fossiliferous, especially those between the two sandstone zones, and contain numerous specimens of such characteristic species of the New York Hamilton as *Spirifer mucronatus* (Conrad), *S. granulosus* (Conrad), *Athyris spiriferoides* (Eaton), *Tropidoleptus carinatus* (Conrad), *Chonetes coronatus* (Conrad), *Phacops rana* (Green), and other species. On account of the presence of numerous Hamilton species together with a lithologic similarity and approximate stratigraphic position, this division of the Romney formation is regarded as equivalent to the Hamilton stage of New York.

The estimates of the thickness of the Romney formation vary from about 1,600 to 1,650 feet. In Allegany county both the Marcellus shale and Hamilton stage are clearly shown; but farther east in Washington county the Marcellus shale or a part of it is wanting. This would indicate that the subsidence of the Onondaga land area began at an earlier date in Allegany than in Washington county.

CORRELATION OF THE MARCELLUS SHALE.

The lithological similarity of the thin, black shales forming the lower part of the Romney formation to the Marcellus shale of New York has been noted in the description of the Romney formation, and in other places in the Maryland volume. This is so marked in connection with its similar stratigraphic position that the northward continuation of these shales in Bedford county, Pennsylvania, were unhesitatingly called the Marcellus by Professor Stevenson in his geological report of that county. Following the northeasterly

strike of the Devonian formations across Pennsylvania, a similar lithologic and stratigraphic shale has been noted by various geologists at different localities, until Monroe county in the northeastern part of the state is reached, where it was positively identified by Dr. I. C. White. The localities in the northeastern part of the state were later studied by the writer, who from the lithologic, stratigraphic, and paleontologic evidence fully accepted Dr. White's correlation.[1] This practically carried the black shale into southeastern New York, where the identification of the black, fissile shale below the Hamilton beds as the Marcellus has not been questioned. Finally, in the Cumberland basin of Maryland Mr. Schuchert positively identifies this shale as "the Marcellus stage of the Middle Devonic," which he states "rests directly upon the eroded Oriskanian."[2]

These shales in general are sparingly fossiliferous in Maryland and northern West Virginia; but there are occasional layers in some localities which contain a more abundant fauna. There may be a question whether the fossiliferous zones noted at certain localities are not stratigraphically above the very fissile bituminous shale so well exposed in the southern part of the Baltimore & Ohio Railroad cut at Twenty-first Bridge, which agrees so strikingly with the Marcellus shale of New York. The writer has studied to some extent the fauna found mainly in the shales which lithologically closely agree with the New York Marcellus. Dr. J. M. Clarke has probably a larger collection, obtained in part from the fossiliferous layers mentioned above, which he is elaborating, and consequently this is to be regarded as only a preliminary account of this fauna.

Twenty-one species have been listed by the writer from these shales, three of which are restricted to Maryland.[3] The other eighteen either occur in New York or are represented by closely affiliated species. These species range in New York from the Schoharie grit to the Chemung, inclusive, and the formations containing the largest number of them, which therefore become the most important in correlation, are as follows: Marcellus, 10 identical, 4 affiliated;

[1] *Bulletin No. 120* (1894), U. S. Geological Survey, p. 4.

[2] *Proceedings of the U. S. National Museum*, Vol. XXVI (1903), p. 422.

[3] Tables giving the geological range and geographical distribution of the Romney species will be published in the Maryland Devonian volume.

Hamilton, 8 identical, 6 affiliated; Sherburne, 2 identical, 3 affiliated; Ithaca, 8 identical, 3 affiliated; and the Chemung, with 3 identical, and 2 affiliated. It will thus be seen that, so far as this fauna is concerned, it indicates the correlation of this shale with the Marcellus shale and Hamilton beds of New York, with the evidence somewhat in favor of the Marcellus, since it contains 10 identical species to 8 in the Hamilton. The weight of evidence in favor of correlation with the Marcellus shale is strengthened when the list is examined a little more closely. *Liorhynchus limitare* (Vanuxem), which, so far as I am aware, is confined to the Marcellus shale in New York, and perhaps may be considered its most characteristic fossil, or at least its most distinctive Brachiopod, is found generally in the black, fissile shale constituting the lower part of the Romney formation in Maryland. *Bactrites aciculatus* (Hall) is known only in the Marcellus of New York, and the *Agoniatites expansus* (Vanuxem) is so characteristic of a thin layer of limestone in the lower Marcellus of New York that it has been named the Agoniatite limestone. In Maryland 170 feet or more above the base of the black shales are thin limestones which also contain *Agoniatites expansus* (Vanuxem).

Finally, it may be said that, so far as the paleontological evidence is concerned, it shows a close relationship between the Maryland black shales and the Hamilton beds of New York, and Dr. John M. Clarke has already shown that such a relation exists in New York, since a large percentage of the species found in the Marcellus shale of that state occurs in its Hamilton beds.[1] The paleontological evidence, however, shows a still closer relationship with the Marcellus shale fauna of New York, which is supported by the visible continuity, lithologic similarity,[2] and stratigraphic position of the containing shales, so that the correlation of this Maryland black shale with the Marcellus shale of New York appears to be fairly well sustained.

CORRELATION OF THE HAMILTON BEDS.

The rocks overlying the Marcellus shale of the Romney formation, and extending northeasterly from northern West Virginia across

[1] *Eighth Annual Report of State Geologist of New York*, 1889, pp. 60, 61.

[2] For a summary of the various methods of correlation see Mr. Gilbert in *Compte rendu*, Fifth Session, International Geological Congress, 1893, pp. 151–54.

Maryland and Pennsylvania to New York, have been much more frequently correlated with the Hamilton beds of New York. Professor James Hall and other paleontologists have identified collections of fossils from these rocks in northern West Virginia, and from intermediate localities between that state and New York, as composed of Hamilton species. If the various geological maps, reports, and papers describing the Devonian formations from West Virginia to New York are put together and considered, it will be found that this correlation is strongly supported by visible continuity. Furthermore, the stratigraphic position of these beds strongly supports this correlation.

The paleontological data are as yet much more extensive regarding the Hamilton beds than for the Marcellus shale. The total number of species recorded by the writer from the Hamilton beds of Maryland is 147, of which 21 are limited to Maryland, leaving 126 identical or closely related species which also occur in New York. An enumeration of the totals for the New York Devonian formations shows that 3 identical species occur in the Helderbergian series; 1 identical, in the Oriskany; 6 identical, in the Schoharie; 17 identical, doubtfully 4 more, and 2 affiliated, in the Onondaga; 47 identical, 1 more doubtfully, and 7 affiliated, in the Marcellus; 92 identical and 32 affiliated, in the Hamilton; 2 identical, in the Tully; 4 identical and 1 affiliated, in the Genesee; 2 identical, in the Portage; 4 identical and 2 affiliated, in the Naples; 10 identical and 1 affiliated, in the Sherburne; 55 identical, 2 more doubtfully, and 9 affiliated, in the Ithaca; and 18 identical, 4 more doubtfully, and 3 affiliated, in the Chemung. Adding these numbers, the total number of entries for each New York formation is as follows: Helderbergian series, 3; Oriskany sandstone, 1; Schoharie grit, 6; Onondaga limestone, 23; Marcellus shale, 55; Hamilton beds, 124; Tully limestone, 2; Genesee shale, 5; Portage beds, 2; Naples beds, 6; Sherburne sandstone, 11; Ithaca beds, 66; and the Chemung beds, 25. Judging from the number of entries, it is then seen that the Maryland beds show the closest relationship with the Onondaga, Marcellus, Hamilton, Ithaca, and Chemung formations of New York; and especially with the Marcellus, Hamilton, and Ithaca. On examining the total number of entries for these three formations, it is found that the Marcellus has 44.3 per cent. as

many as the Hamilton, and the Ithaca 52.8 per cent. This is not remarkable, however, when it is recalled, in the first place, that a large percentage of the species in the Marcellus shale of New York continue into the Hamilton beds of that state, as has been shown by Dr. John M. Clarke; and, in the second place, that the Ithaca fauna is sequential to the Hamilton, and in the Ithaca region contains a large percentage of Hamilton species. When followed to the eastward, and after the disappearance of the Tully limestone and Genesee shale in the Chenango valley, the writer has shown that a still larger number of the Hamilton species lived into Ithaca time, although part of them were represented by simply a few individuals which were the last feeble representatives of their species. These rare individuals have been recorded in the range of the species, making the faunas of the Hamilton and Ithaca beds of New York seem more closely related than they actually are; and the same is true regarding the faunas of the Maryland beds and the Ithaca beds of New York. This explanation is sufficient to show that the above tabulation gives full expression to the closeness of the relationship which exists between the fauna of the Maryland beds and the faunas of the Marcellus shale and Ithaca beds of New York, as compared with that which exists between the fauna of the Maryland beds and the New York Hamilton fauna. Restating the tabulation, then, it is shown that there are more than twice as many entries common to the Maryland and New York Hamilton beds than to the Maryland and New York Marcellus; and nearly twice as many for the Maryland and New York Hamilton beds as for the Maryland and New York Ithaca. Therefore the paleontological evidence strongly supports the correlation of the Maryland beds, which represent in general the midddle and upper portions of the Romney formation, with the Hamilton beds of New York.

Recently Professor H. S. Williams has published an extended account of what he calls the *Tropidoleptus carinatus* fauna of the Hamilton formation.[1] Faunally he considers the Hamilton formation as including the deposits between the top of the Onondaga limestone and the base of the Tully limestone of central New York, which

[1] *American Journal of Science*, Fourth Series, Vol. XIII (1902), pp. 421–32; *Bulletin No. 210*, U. S. Geological Survey, 1903, pp. 42–68.

have generally been divided into the Marcellus shale and the Hamilton beds. Professor Williams compiled a list of twelve species for the *Tropidoleptus* fauna which he called the "standard list of dominant species for the New York-Ontario province." Another list was also compiled, which he called a "revised list of dominant species of the Hamilton formation of eastern New York and Pennsylvania, as expressed in 183 faunules," which contained the twelve species given in the standard list and four additional ones. All of these sixteen species occur frequently in the Hamilton beds of Maryland.

Professor Williams, after an examination of the preliminary lists from the Hamilton beds of Maryland, published the following statement:

> In the list furnished me by Professor Prosser there appear 132 entries, 91 of which are positive identifications. Among the latter are found all of the dominant species of the *Tropidoleptus carinatus* fauna, as estimated from the New York statistics. This is sufficient to establish the extension of the *Tropidoleptus* fauna, in its integrity, as far south in the Appalachian trough as Maryland.[1]

Other facts brought out in the Maryland Devonian report by Dr. John M. Clarke and the writer apparently show that the Hamilton beds of Maryland are succeeded by deposits and faunas similar to those succeeding the Hamilton of New York, and therefore it may be concluded that the deposits of the Hamilton beds from New York to West Virginia were brought to a close at about the same geological time.

EUROPEAN EQUIVALENTS.

The early attempts at correlating the Devonian rocks of the United States with those of Europe dealt only with the formations found in New York, which, in fact, has generally been the custom down to the present time. In 1842 Conrad published the statement that "the Ithaca group, Chemung group, and the Old Red Sandstone near Blossburg, in Pennsylvania, constitute the equivalents of the Devonian system as developed in Europe," and contain a number of fossils characteristic of European Devonian strata.[2] The same year Vanuxem stated that the last three groups of the "Erie Division"

[1] *Bulletin No. 210*, U. S. Geological Survey, p. 67.

[2] *Journal of the Academy of Natural Science*, Philadelphia, Vol. VIII, p. 232.

—viz., the Portage, Ithaca, and Chemung—"appear to correspond with the Devonian system of Mr. Phillips."[1] The following year Professor Hall gave the base as somewhat lower when he stated that the Devonian system appears "to correspond to the Chemung and Portage groups, and also to include a portion of the Hamilton."[2] In 1847 Professor Hall stated that

With the Schoharie grit, commences a series of strata containing fossils as distinct from those of the preceding formations, as these are from the lower division. We here, for the first time, recognize several species that are regarded as Devonian forms; and if zoölogical characters are to be paramount, we are compelled to unite all the succeeding strata as of Devonian age.[3]

Finally in 1859, he raised the question whether even the Oriskany sandstone might not be considered as of Devonian age. For he wrote as follows concerning

the line of demarkation for the Silurian and Devonian systems. Shall the advent of the Oriskany sandstone, with its *Spirifer* of dichotomizing costæ, be the division? Or shall we look for some more marked and more readily defined and recognized feature for the distinction between what are regarded as two great geological systems?[4]

So far as the writer is aware, de Verneuil in 1847 was the first geologist definitely to correlate the younger formations of the New York system with subdivisions of the Devonian system of Europe. He made the base of the Oriskany sandstone the dividing line between the Devonian and Silurian systems;[5] correlated the Hamilton, Tully, Genesee, Portage, and Chemung with the formations of the Eifél and Devonshire, and the Marcellus with the shales of Wissenbach in Nassau, as is proved by their Goniatites, so analogous in form.[6]

In recent years several geologists have considered the correlation of the American Mesodevonian with European rocks of equivalent age, of which the following are the most important:

[1] *Geology of New York*, Part III, p. 171.

[2] *Ibid.*, Part IV, p. 20.

[3] *Palæontology of New York*, Vol. I, p. xvii.

[4] *Ibid.*, Vol. III, Part I, p. 42.

[5] *Bulletin de la Société Géologique de France*, Second Series, Vol. IV, p. 677; also *American Journal of Science*, Second Series, Vol. V (1848), p. 367, on the parallelism of the Palæozoic deposits of North America with those of Europe, translated by JAMES HALL.

[6] *Loc. cit.*, p. 678; and *American Journal of Science, loc. cit.*, pp. 367, 368.

In 1889 Professor H. S. Williams apparently correlated in a general way the American Middle Devonian with "the Ilfracombe [England] beds of Phillips, the Givétien limestone of Belgium, [and] the Stringocephalien shales or limestones of the Eifél and Hartz regions."[1] In 1888 Professor Williams examined in the field typical sections of the Devonian rocks of Devonshire, England, and later stated that "it appears probable that the limestones of South Devonshire represent the general interval between the close of our Corniferous [Onondaga] and the early part of our Chemung formation."[2] Professor Renevier in 1896 classed the Hamilton flags and Marcellus shales together and regarded them as having been deposited during the same general period of time as the *Tentaculite* slates (lower part) of Thuringia, Hesse, Nassau, and Bohemia; the Wissenbach or *Orthoceras* slates of Nassau; the Lenne slates (in part) of southern Westphalia; and the schists with *Phacops potieri* of Brittany; all of which were correlated with the Couvinien age or stage, which he gave as the lower one of the Middle Devonian or Eifélien epoch or series.[3]

Dr. Frech draws the line between the Paleodevonic and the Mesodevonic of New York at the top of the upper Oriskany sandstone, and considers the Mesodevonic as composed of the Ulsterian and Erian seris, in the latter of which are the Marcellus shales, Hamilton beds, and *Stringocephalus* beds of Canada.[4] At an earlier date Dr. Frech, in his summary of the important occurrences of the Devonian, gave the Marcellus shale and Hamilton group as forming the upper part of the Middle Devonian, and correlated them as beginning in the time of the upper part of the *Calceola sandalina* stage and continuing through that of the *Stringocephalus burtini* of Rheinland.[5] In this same table the Marcellus and Hamilton considered together are correlated with the upper part of the Eifélien (*Calceola* shales

[1] *Compte rendu*, Fourth Session, International Geological Congress (London, 1888), 1891, Appendix A, p. 142; also issued as *Report of the Sub-Committee on the Upper Paleozoic* (*Devonic*), by H. S. Williams, C, 1889, p. 22.

[2] *American Journal of Science*, Third Series, Vol. XXXIX (1890), p. 36.

[3] *Chronographe géologique*, 2d ed. of *Tableaux des terrains sedimentaires; Compte rendu*, Sixth Session, International Geological Congress (Zurich, August, 1894); Lausanne, March, 1897).

[4] *Lethaea geognostica*, I, *Lethaea palaeozoica*, Vol. II, Part IV (1902), p. 690.

[5] *Ibid.*, Vol. II, Part I (1897), Table XIX, opposite p. 256.

of Couvin) together with the entire Givétien (which is composed in ascending order of the red sandstone and conglomerate of Vicht and *Stringocephalus* limestone of Givét) of Belgium; while they are given as equivalent in England to the Ilfracombe beds, with probably additional ones below and above, of North Devon; and to the upper part of the *Calceola* shales of Hopes Nose and Ogwell House, succeeded by the diabase and scale stone of the Ashfrington series and the *Stringocephalus* limestone of South Devon.

In another part of the work Dr. Frech, in comparing the North American and Rhenish Devonian, said:

> In the Corniferous [Onondaga] limestones the faunal diversity is less sharply defined than in the lower formations; but in this case, as in the higher Hamilton group, still distinctly perceptible. The latter is often developed in the form of sandy marl and calcareous sand, and the peculiar faunal similarity with the Rhenish Lower Devonian partly rests upon this harmony in facies. But, on the other hand, the marl (Moscow shale), for example, where it forms on Cayuga Lake the greater part of the Hamilton, has a perfect agreement in facies with the *Calceola* marl, and likewise the Encrinal limestone reminds one of a similar interstratified limestone. . . . . The fauna of the American Middle Devonian, whose chief representatives the Hamilton group contains, is, notwithstanding some corresponding features, yet, on the whole, so different that one must assume the existence of a special sea province also in Middle Devonian time differing from the Rhenish.[1]

Finally, at the close of this section is the statement that the Marcellus shale corresponds to the lower part of the stage of the *Maeneceras terebratum*[2] of Rheinland, which Dr. Frech puts in the stage of the *Stringocephalus burtini*.

De Lapparent considers the Middle Devonian of North America as composed of the Corniferous (Onondaga) limestone, Marcellus shale, and Hamilton beds.[3] The Marcellus shale he correlates with the upper part of the Eifélien stage and the lower part of the Givétien, while the Hamilton beds represent the remaining and greater part of the latter stage. He also gave the lower Marcellus shale as representing the upper part of the shales of Ogwell House, and then the remaining portion together with the Hamilton beds as synchronous with the Ilfracombe or Plymouth beds of Devonshire, England.[4]

Professor Kayser in the table of the Devonian formations of New

[1] *Ibid.*, pp. 214, 215.

[2] *Ibid.*, p. 216.

[3] *Traité géologique*, 4th ed. (1900), p. 857.

[4] *Ibid.*, p. 869.

York, gives the Mesodevonic as composed of the Marcellus shale and Hamilton beds,[1] but in the text he says:

The American geologists generally still classify the Onondaga limestone as Lower Devonian; according to European experience, one would be rather inclined to classify it entirely or mostly as Midddle Devonian. The great similarity of the characteristic *Spirifer acuminatus* Con. with our *S. cultrijugatus* argues for this classification.[2]

Regarding the classification of the Hamilton the professor says:

Although the Hamilton shale locally might represent the entire Middle Devonian, yet, on the whole, it corresponds to the upper division. This is surely shown by the frequent overlying beds of the Tully limestone and Genesee shale, the first of which contians the Brachiopod fauna of our Iberg limestone (*Rhynchonella venustula* =*cuboides*, etc.).[3]

Finally, this writer has given the correlation of the Middle Devonian of Europe and North America in the following table:

RHEINLAND AND BELGIUM.		BOHEMIA.	NORTH AMERICA.
		G^3,	
Stringocephalus limestone, Caleceola shales.	Wissenbach and Lenne slates.	G^2,	Hamilton beds,
		G^1,	Marcellus beds,
		Mnenian limestone.	
			Onondaga limestone[4]

Dr. Hermann Credner gives the Middle Devonian of New York as composed in ascending order of the Upper Helderberg (Onondaga), Marcellus shale, and Hamilton sandstone, shale, and limestone. The Upper Helderberg he correlates with the Eifélien and stage of the *Calceola sandalina*, and the Marcellus and Hamilton with the Givétien and stage of the *Stringocephalus burtini*.[5]

Sir Archibald Geikie considers the Middle Devonian of New York as composed of the Marcellus and Hamilton groups,[6] while the same division in Europe he gives as composed of the Eifélien and Givétien, with which he correlates the Marcellus and Hamilton.[7]

GENERAL DISTRIBUTION OF THE MESODEVONIAN.

Rocks of the Mesodevonian age have a considerable distribution, aside from that of the eastern United States and Canada, for they

[1] *Lehrbuch der geologischen Formationskunde*, 2d ed. (1902), p. 150.

[2] *Ibid.*, p. 151. [3] *Ibid.*, p. 151. [4] *Ibid.*, p. 155.

[5] *Elemente der Geologie*, 9th ed. (1902), p. 447.

[6] *Text-Book of Geology*, 4th ed., Vol. II (1903), p. 997.

[7] *Ibid.*, "The Geological Record," opposite p. 861.

have been identified and described in Nevada; the dolomite of Manitoba contains the European species *Stringocephalus burtini; Spirifer mucronatus* has been found upon the banks of the Albany River south of Hudson Bay; the fauna of the Hamilton shales occurs in the Mackenzie Valley from the Clear Water River to the Arctic Ocean; while it is also reported from the Porcupine River, a western tributary of the Yukon in Alaska, and perhaps also on Kouiou Island, in the southern part of that territory. In South America, in Brazil, in the province of Para, in the Ereré district, are beds which Katzer refers to the base of the Middle Devonian, and Dr. J. M. Clarke has stated regarding the fauna of the Ereré sandstone that it

> is remarkably free from species or representatives of subgeneric groups prevailing elsewhere in early Devonian faunas, and equally devoid of types which elsewhere pass upward into the later faunas; in other words, it is, with all its resemblance to the Hamilton, a more typical and better-defined Middle Devonian fauna than that;[1]

while Dr. Frech reports Middle Devonian in Bolivia and Cleland from the Jachel River in Central Argentina.[2] On the eastern continent Middle Devonian rocks occur in England in northern and southern Devonshire, in northern France and southern Belgium, in the region of the Vosges, in the Central Plateau and the Montagne-Noire of France, and in the Pyrenees and Spain. In central and eastern Europe they occur in the Eifel, Rheinland (Nassau), Hartz, Thuringia, Bohemia, Galicia, Russian Poland, the Carnic Alps, and on the Bosporus. These rocks also cover a large area of eastern Russia and the western slope of the Urals, extending to the border of Finland on the north. In Asia Middle Devonian rocks occur in Siberia, China, and on the south side of the Tian-Shan Mountains in Central Asia. In Australasia they are found in New South Wales, Victoria, and Tasmania; and they also probably occur in Africa.[3]

CHARLES S. PROSSER.

OHIO STATE UNIVERSITY,
Columbus, Ohio, July, 1904.

[1] *Archivos do Museu Nacional do Rio de Janeiro.* Vol. X (1899); author's English edition (1900), p. 90.

[2] *Bulletin No. 206,* U. S. Geological Survey, (1903) p. 19.

[3] For this account of the distribution of the Mesodevonian the writer is largely indebted to DE LAPPARENT'S *Traité de géologie,* FRECH'S *Lethaea palaeozoica,* and KAYSER'S *Lehrbuch der geologischen Formationskunde.*

GRANITES OF NORTH CAROLINA.[1]

CONTENTS.

[1] Published by permission of the state geologist of North Carolina.

INTRODUCTION.

THE following paper is based on a study of the granites and gneisses of North Carolina during the past field season, while I was engaged on the State Geological Survey in a field study of these rocks. The economic report treating of the granites has been prepared and will form a part of a general report on the building-stones of North Carolina to be published by the State Survey. A general summary setting forth the more important points in the petrography and structure of these rocks is offered in the present paper as a separate contribution.

DISTRIBUTION OF THE GRANITES.

North Carolina is divisible naturally into three principal physiographic provinces, which, named in order from east to west, are: the Coastal Plain, the Piedmont Plateau, and the Appalachian Mountains. These form a part of the continuation of the same provinces to the north and south of North Carolina; and they observe approximate parallelism with each other and with the general trend of the coast line of the southeastern Atlantic states. The granites of North Carolina are distributed over parts of each of these three provinces; the areas being fewer and smaller over the Coastal Plain region, and more numerous and larger over the Piedmont Plateau region. Gran-

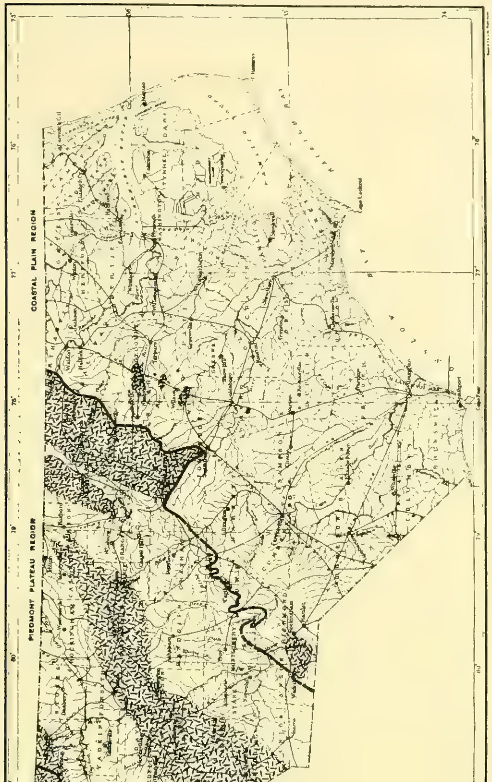
COASTAL PLAIN REGION
PIEDMONT PLATEAU REGION
MOUNTAIN REGION

Fig. 1.

ite is extensively developed in many places, within the limits of the Piedmont Plateau, and it forms over many parts of the plateau one of the dominant rock types. The distribution of the principal granite areas of the state is shown on the accompanying map.

Over all parts of the state the rocks are profoundly decayed from weathering and, as a rule, are buried under a deep mantle of loose residual decay. Notwithstanding the extensive decay of the rocks, exposures of the moderately fresh granite are comparatively numerous and assume oftentimes very large dimensions. The granite forms unreduced residuals or ridges, as shown in Fig. 7, and it is further exposed in bowlders and ledges and flat-surface masses, both along the stream courses, and more or less remote from the streams on the interstream areas. (Figs. 2 and 3.)

Numerous quarries have been worked in the outcrops of granite throughout the state, and the stone has been used for all purposes for which granite is ordinarily adapted.

TYPES OF THE GRANITES.

Based on texture and structure three types of the granitic rocks are distinguished: (1) the massive even-granular (normal) granites; (2) the porphyritic granites; and (3) the banded or schistose granites—granite-gneiss. Field and laboratory study develops close similarity in the three types in mineral composition, and, with one exception, the even-granular and porphyritic textures represent different phases of the same rock-mass. Moreover, the granite-gneisses differ essentially from the massive granites, from which they have been derived, only in the pronounced schistose structure subsequently induced by pressure-metamorphism.

NORMAL GRANITES.

The even-granular granites have wide distribution, and they compose largely the bulk of the granites occurring in North Carolina. As a rule, they vary from fine- to medium-textured rocks, rarely coarse, and are of pink to gray color. With only a few exceptions, light to medium and dark gray is the prevailing color of the granites. Variation in structure is from massive to schistose rocks. They are mixtures of orthoclase and plagioclase feldspars and quartz, with a

variable quantity of biotite and, in places, some additional hornblende as the characterizing accessories. The prevailing large amount of plagioclase feldspar in the rocks is a very noteworthy feature; rarely does this constituent sink to very subordinate proportions, but usually it is almost equal to, or even exceeds in amount, the potash

FIG. 2.—Granite bowlders on Dunn's Mountain, near Salisbury, North Carolina. Showing weathering along the joint-planes.

feldspars; and only in a few of the sections studied does it entirely fail. In many of the areas the poverty of the rocks in the ferromagnesian silicates is a striking feature—a fact well illustrated in the large and important granite area in Rowan county, known as Dunn's Mountain, and its southwestern extension.

PORPHYRITIC GRANITES.

In all respects save that of texture the porphyritic granites are identical with the normal granites. They are usually coarser in texture than the even-granular rocks, but mineralogically the two are

identical. With one exception, the two textures grade one into the other, representing different textural phases of the same rock-mass.

Porphyritic granites have wide distribution over the state in association with the even-granular phases of the rock. The most important areas are: (1) The Wadesboro-Rockingham area to the east of Charlotte and near the South Carolina line, extending over contiguous parts of Anson and Richmond counties. Over parts of this area the feldspars are colored a rich olive-green, representing apparently a superficial phenomenon caused by some form of surface alteration. A second difference noted is in the distribution and character of the biotite, which occurs in hexagonal plates of single or grouped individuals occupying distinct areas. (2) The Gastonia area in Gaston county, west of Charlotte. (3) The Mooresville area in Iredell county. (4) The Cabarrus county area, three miles southwest of Concord; and a second area in the same county in the vicinity of Landers station on the Southern Railroad, to the north of Concord and near the Rowan county line. The porphyritic rock occurring three miles southwest of Concord is quite different in appearance from that of any other area of porphyritic granite known in the state. Here the rock is uniformly coarse-textured and largely feldspathic, composed of large bluish-gray feldspars without pronounced crystal outline. The rock contains hardly more than a trace of groundmass, but is made up chiefly of the large feldspars wrapped about each other and closely interlocked. Biotite in small irregular shreds is one of the chief minerals in the scant groundmass. (5) The Salisbury area, which forms one of the most extensive belts in the state and is traced over parts of Rowan, Davie, and Forsyth counties. Smaller and less important areas of similar porphyritic granite have been noted in several other counties in the state.

Excepting the area three miles southwest of Concord in Cabarrus county, the porphyritic granite of the different areas mentioned above is closely similar in color, texture, and mineral composition. The groundmass is usually a medium-coarse gray granite composed of feldspar, quartz, and biotite. Some variation in the amount of the last constituent, biotite, is noted from place to place, resulting in a corresponding variation of color from light to dark gray. The porphyritically developed mineral is potash feldspar. As a rule,

phenocrysts are marked in the different areas by idiomorphic outlines; and they are prevailingly of large size, measuring in extreme cases more than two inches long by one inch across. They are usually white, with pinkish ones not uncommon, and, in most cases, they contain more or less included biotite, frequently as large in size as

FIG. 3.—Granite pinnacle on the west slope of Dunn's Mountain, near Salisbury, North Carolina. Height of pinnacle more than twenty-five feet.

that of the groundmass constituent. Under the microscope other inclusions of the groundmass constituents are contained in some of the phenocrysts. For this and other reasons elsewhere[1] stated by me, the phenocrysts of the Carolina porphyritic granites are regarded as having been formed largely, if not entirely, *in place* and not as often urged of *intratelluric* origin.

Generally the phenocrysts do not grade into the similar groundmass constituent, but they are, in most cases, conspicuously developed

[1] "On the Origin of the Phenocrysts in the Porphyritic Granites of Georgia," JOURNAL OF GEOLOGY, Vol. IX (1901), pp. 97–122.

and are sharply defined from the groundmass feldspar. No marked or definite orientation has been observed among the phenocrysts in any of the areas, but in some of the exposures a slight tendency toward such was indicated. Flow structure in the groundmass is entirely absent from all of the areas studied.

The porphyritic feldspars almost entirely fail in places, reappearing again within a short distance in their usual abundance and of conspicuous development. Over most of the areas the probable average ratio of phenocrysts to groundmass is approximately one to one, though extreme variations from this ratio in either direction occur. In the transitional phases of the rock where gradation from the porphyritic to the even-granular texture is observed, the phenocrysts are so few and are so widely scattered that the rock could hardly be termed porphyritic. On the other hand, in the porphyritic granite area three miles southwest of Concord, in Cabarrus county, the rock is composed almost entirely of the large feldspar individuals with very scant groundmass. In all cases the phenocrysts display good cleavage development and twinning on the Carlsbad law.

In many of the areas where outcrops of the fresh or moderately fresh granite are few, the rock can be traced almost as readily by its residual decay. The loose phenocrysts are scattered over the surface in places in a partially altered condition, often split into smaller fragments along the cleavage directions.

Relations between the porphyritic and the even-granular granite in the Mooresville area.—Like the other areas studied, the porphyritic and non-porphyritic granite of the Mooresville area differ from each other only in texture. Without going into detail descriptions of the two texturally unlike rocks, evidence is afforded at several places to the south and the southwest of Mooresville for regarding the one as intrusive in the other, and they do not represent separate facies of the same granite mass. Were the latter true, the line between the two rocks should mark a transitional zone from the porphyritic to the non-porphyritic granite, and not indicate in the few exposures examined a sharp contact. Furthermore, certain phenomena along this line would be difficult of explanation on this supposition. On the other hand, the evidence strongly suggests that the porphyritic rock is the oldest, and that the even-granular granite is intrusive in it. The field

evidence supporting this belief may be summarized as follows: the sharpness of contact between the porphyritic and the non-porphyritic granite; the prevailing coarser texture of the porphyritic granite along the line of contact than that of the non-porphyritic rock; the banding in places along the contact; inclusions of the porphyritic granite in the even-grained granite; and the occurrence of probable apophyses of the fine-grained granite penetrating the porphyritic granite.

GRANITE-GNEISS.

True granite-gneisses are found in many places over the state, but perhaps the most typical areas are: (1) the unreduced residual locally known as Rockyface Mountain in Alexander county; (2) the area near Balfour station in Henderson county; and (3) the area on the Josey-Bogers places, three miles southwest of Faith in Rowan county. Wherever studied, the granite-gneisses are biotite-bearing, fine to medium texture, and closely resemble the massive granites in all essentials except that of schistose structure. Some effects of pressure-metamorphism are indicated either megascopically or microscopically in the granites of most of the areas studied. Granites of complete schistose structure were not definitely traced in any single area into entirely massive ones, although this may be the real condition in many cases. Lack of sufficient exposures of the rocks renders this uncertain in the North Carolina areas.

RELATIONS BETWEEN THE THREE TYPES OF GRANITE.

Enough description has been detailed above under the even-granular, porphyritic, and schistose granite to make fairly clear, so far as the field study is possible, the relations between the three texturally and structurally unlike granites here distinguished. It seems reasonably certain, so far as I have been able to interpret the field relations, that the porphyritic and non-porphyritic granites represent, with one or two possible exceptions different facies of the same granite mass. The principal exception noted above is that of the Mooresville area in Iredell county, where the normal granite is intrusive in the porphyritic granite.

The exact relations of the schistose (granite-gneisses) to the even-granular massive granites are less clear, and for lack of adequate

exposures no definite statement can be made regarding whether the granite-gneisses are the more schistose transitional portions of a more massive granite stock. The completely schistose structure has nowhere been positively traced into the more massive granites, though this may be the true relation. That the areas of schistose granites mentioned above are the metamorphosed equivalents of the massive granites apparently admits of no reasonable doubt.

As pointed out in my study of the Georgia granites,[1] the exact relationship is an important one as bearing on the question of the relative age of these rocks. If the schistose rocks (granite-gneisses) cannot be traced into granites of more massive structure, but the two are separate and distinct, then clearly two periods of intrusion must be admitted, separated by an interval of intense pressure-metamorphism, which resulted in inducing the secondary schistose structure in the earlier massive granites, represented, if the postulate is correct, by the present granite-gneisses. If, on the other hand, the two represent phases of the same rock-mass in which the action of dynamic forces has been greater in some parts of the massif than in others, then the same age must be assigned them. As elsewhere shown in my study of the Georgia granites, the first condition apparently obtained, and the granites are not all of the same age; but at least two separate periods of intrusion of nearly identical material are indicated.

GRANITES OF THE COASTAL PLAIN REGION.

GENERAL CHARACTERS.

The line marking the contact between the Coastal Plain and the Piedmont Plateau formations in North Carolina is a very irregular one. It enters North Carolina from Virginia a short distance east of the Warren county line and crosses the state in a general southwest direction, passing into South Carolina a short distance southwest of Wadesboro. To the east of this line are the loose unconsolidated formations of the Coastal Plain.

In many places near the contact of the Coastal Plain formations with the rocks of the Piedmont Plateau, but falling well within the

[1] "Granites and Gneisses of Georgia," *Bulletin No. 9-A*, Geological Survey of Georgia, 1902.

limits of the former, the thin veneer of loose unconsolidated sands and gravel has been stripped from the surface, mainly along the streams, exposing comparatively small, irregular, somewhat elongate areas of the crystalline rocks, composed either in part or in whole of granite. In such areas the general nature of the granite exposures is in the form of ledge and bowlder outcrops, and as flat-surface masses a short distance back from the streams.

The inliers of crystalline rocks mark the eastward extension of the Piedmont crystallines beneath the Coastal Plain sediments. Some of the schists and gneisses composing parts of these areas are the metamorphosed equivalents of original igneous masses. They include both acid and basic types.

The principal granite areas of the Coastal Plain are exposed in Wilson, Edgecombe, and Nash counties to the east of Raleigh, and in Anson and Richmond counties in the vicinity of Wadesboro near the South Carolina line. They are composed of massive biotite granites, in one instance hornblende-bearing, which vary from fine even-granular to coarse porphyritic rocks of gray to pink color. The area to the north of Elm City, in the extreme northern part of Wilson county, contains some hornblende in addition to the biotite.

LITHOLOGICAL CHARACTERS OF THE GRANITES.

The Coastal Plain granites are described separately by areas in order to bring out more clearly their close similarity to the granites of the Piedmont region.

The Wilson pink granite area.—The rock is uniformly coarse-textured, of moderate pinkish-red color, and displays a pronounced porphyritic tendency. Feldspar is greatly in excess of the other minerals. The largest feldspar individuals measure one to two inches long. They are pinkish-red in color, exhibiting good cleavage development and twinned on the Carlsbad law. Microscopically the feldspar and quartz make up not less than 95 per cent. of the rock. A rough estimate indicates about 80 per cent. of the former and 15 per cent. of the latter. Of the feldspathic content about 50 per cent. is potash feldspar, most of which is orthoclase, with but little microcline; and 30 per cent. is plagioclase in very large, finely striated laths, whose extinction angles measured against the twinning bands indicate

albite. Biotite is but sparingly present in the rock and is largely altered to chloride. Occasional small grains of magnetite and scattered inclusions of prismatic apatite, with some secondary muscovite, kaolin, and calcite, complete the list of accessories.

The weathered surface of the granite is light in color. The feldspars are dull and opaque, and have lost much of their decided pinkish-red color, so characteristic of the same constituent in the fresh rock.

The Elm City area.—The Elm City granite is strongly contrasted with the Wilson pink granite described above. It is much finer in texture, of gray color, and contains more biotite and quartz than the Wilson pink granite. Feldspar predominates and consists of the potash varieties and much striated acid plagioclase. Extinction angles measured on the plagioclase correspond to an albite of the composition $Ab_{12}An_{1}$. Areas showing alteration to kaolin and muscovite cloud some of the feldspars. Micropoikilitic structure is strongly developed in some of the larger individuals of potash feldspar, the inclusions of which consist of large microscopic grains of quartz and striated feldspar. Quartz is of the usual kind, forming distinct areas of an interlocking finer mosaic. Biotite is distributed through the sections as small plates of brown color and strong pleochroism, bleached to green on alteration, and is further altered to chlorite and some epidote. In one of the thin sections a few additional small crystals of compact hornblende, showing the usual development of the prismatic cleavages, occur. The principal accessories include zircon, apatite, a little pyrite, titanite, and ilmenite. The granite shows evidence both megascopically and microscopically of dynamic metamorphism, manifested, in places, by a rather pronounced schistose structure.

The quarry opening indicated penetration of the granite by a dike of very finely schistose amphibolite, closely jointed and containing many disseminated small grains of pyrite. Additional quartz veins penetrate the granite, wrapped, in cases, by films of thin layers of hornblende. The surfaces of the joints are slickensided, coated with a thin veneer of yellowish-green mineral substance, probably epidote in part. Considerable epidotization characterizes the rock in places.

The Rocky Mount area.—Westward from Rocky Mount the granite is associated with an irregular but large body of crystalline schists

which were derived in part from original igneous rocks. Contacts between the granite and the schists were nowhere observed, but the field evidence clearly suggests that the granite is the younger rock.

Pegmatite veins, ranging from a fraction of an inch to more than six inches across, composed of pinkish feldspar and quartz, with a very subordinate amount of biotite, penetrate the granite. Nearly all gradations from those veins containing mostly feldspar to those containing mostly quartz occur. In some of the veins the quartz forms a narrow central band in the feldspar. Others still are banded with a fine-textured granite of the same mineral composition as the inclosing rock. Some of these are true veins of segregation; others are less certain of interpretation, mainly because of the lack of exposures for examining them.

Megascopically the rock is somewhat unlike that described above, the Elm City area. It is entirely massive, of medium texture, and gray color. In mineralogy it differs from the Elm City rock in the entire absence of hornblende, and in the presence of only a slight amount of plagioclase. Orthoclase and microcline have nearly equal distribution. Quartz forms a fine mosaic, occupying distinct areas. Intergrowths of micrographic structure are rather abundantly distributed through the sections in irregular small areas. The accessory minerals are biotite, chlorite, epidote, apatite, zircon, and magnetite.

The Wadesboro-Rockingham porphyritic granite area.—This is a large area of porphyritic granite lying partly in Anson and partly in Richmond county, near the South Carolina line and to the west of Charlotte. About one mile east of the westernmost exposure of the granite the Triassic sandstones first appear, overlying unconformably the crystalline schists. Between the granites and the sandstones is an area of variable crystalline schists, principally micaceous and quartz schists. Between Rockingham and the easternmost outcrops of the granite the rocks are concealed by Coastal Plain sands and afford no evidence of the nature of the underlying crystallines. In and about the town of Rockingham the principal outcrops indicate a greenstone schist much crushed and fractured, and strongly suggests derivation from an original basic igneous rock. The schists to the east and west of the granite mass must be regarded as older in age

than the granites, and they form the country rock into which the granite was intruded.

Exposures of the granite are in the nature of huge bowlders, ledges, and flat-surface masses. Sections of the fresh and weathered granite are seen to advantage in the cuts along the Seaboard Air-Line Railroad to the east and west of Lilesville.

It is a coarse-grained porphyritic biotite granite of gray color, with pinkish and yellow tones characteristic in places. The groundmass is medium coarse-textured, dark gray, granite, containing, as a rule, much biotite. This is subject, however, to some variation. In the railroad cut one and a half miles west of Lilesville the biotite has quite a different occurrence and distribution in the granite from that of any other exposure examined in the area. Here the biotite is usually in sharp idiomorphic hexagonal plates, distributed through the rock as single individuals and aggregates, which occupy distinct areas. Elsewhere it occurs as irregular shreds crowded close together and freely distributed through the groundmass.

The phenocrysts are composed of potash feldspar, showing marked cleavage development and twinned on the Carlsbad law. They are usually of a pinkish hue, and may be either idiomorphic or allotriomorphic in outline; and, they contain usually some included biotite. The ratio of phenocryst to groundmass is variable, but will probably average about one to three.

The principal minerals are quartz, orthoclase, microcline, plagioclase (near oligoclase), biotite, chlorite, apatite, zircon, magnetite, and a few other less common accessories. Microcline may fail in some sections and be present in large proportion in others. Plagioclase is a constant constituent and is usually present in large amount.

GRANITES OF THE PIEDMONT PLATEAU.

GENERAL CHARACTERS.

The Piedmont region in North Carolina is composed of a number of geologic belts, approximately parallel to each other and crossing the state in a general northeast-southwest direction. These belts are composed, as a rule, of unlike rocks, probably of different ages. A variety of granites are found within the limits of the Plateau region; always biotite-bearing, with additional hornblende in some areas,

and muscovite when present in very subordinate amount. In texture, variation is from even-granular to porphyritic; and in structure from massive to schistose. As a rule, some shade of gray prevails, though pink is largely characteristic of certain areas. The Plateau granites are described under the following belts: The Northeastern Carolina Granite Belt, the Main Granite Belt, and the Western Carolina Gneiss and Granite Belt.

THE NORTHEASTERN CAROLINA GRANITE BELT.

This area comprises a part or the whole of five counties located in the extreme northeast part of the Piedmont region, extending northward from Raleigh. With but few exceptions, the granites of this belt are partially schistose in structure. The characterizing accessory, biotite, is variable in quantity; imparting accordingly either a light or a dark gray color to the rock. In places the feldspars are of a pronounced pinkish hue and with the subordinate amount of biotite present, the rock assumes more or less of a mixed pinkish-gray color. The granites are usually even-granular in texture, though the porphyritic tendency is somewhat emphasized in places. They do not differ essentially in mineralogy, although hand specimens from different areas in the belt may bear no resemblance to each other.

LITHOLOGICAL CHARACTERS.

Two areas, differing somewhat widely in the hand specimens, but which may be regarded as representative of the granites of the belt as a whole, are selected for description, in order to make clear the general characters of the rocks as a whole. These are the Raleigh area in Wake county and the Greystone area in Vance county.

The Raleigh area.—Studied in the quarries opened within the eastern limits of the city of Raleigh, the rock is a fine even-textured, medium-gray, biotite granite-gneiss, completely interlaced by intersecting pegmatites. The principal minerals are quartz, orthoclase, microcline, acid plagioclase near oligoclase, brown biotite, muscovite, zircon, apatite, chlorite, and epidote. Quartz is of the usual kind, and is often intergrown with feldspar in micrographic structure, clearly indicating that its period of formation began before that of the feldspar closed. In addition, it occurs with other minerals, especially

plagioclase, in the form of inclusions in the larger potash feldspar individuals developing micropoikilitic structure. Microcline nearly equals orthoclase in quantity, and plagioclase is hardly less than both. Carlsbad twinning is sometimes observed in the feldspar.

Biotite is brown in color, strongly pleochroic, and is largely altered to chlorite and some epidote. An occasional shred of muscovite is intergrown with the biotite. The other accessory minerals present no noteworthy features.

The larger feldspar and quartz individuals are partially or entirely surrounded by finer mosaics of the same minerals, denoting peripheral shattering from dynamic forces. Strained shadows in the minerals are further characteristic of the same pressure effect.

In the northern part of Wake county, in the vicinity of Rolesville, a light pinkish biotite granite occurs, which differs from the Raleigh granite in the hand specimen, but does not differ essentially in mineralogy. Plagioclase is very variable, equaling in some sections the potash feldspar and nearly failing in others. Orthoclase and microcline are in nearly equal proportion. Small irregular areas of micrographic intergrowths of quartz and feldspar are quite abundantly distributed through the thin sections.

The Greystone area.—The Greystone quarries are among the largest in the state. The typical Greystone granite is medium gray in color, of pronounced schistose structure, and in texture varies from fine- to medium-grained. More or less tendency toward a poorly defined porphyritic texture is manifested in some parts of the area. The feldspars are partly of a pronounced pinkish hue, which impart a slightly mixed pink and gray color to the rock. In some respects hand specimens from the Raleigh and Greystone areas bear some resemblance to each other; in others they are strikingly different. In mineral composition they are essentially identical.

The principal minerals are quartz, orthoclase, microcline, microperthite, a little acid plagioclase near oligoclase, biotite, apatite, zircon, chlorite, muscovite, and kaolin. Microscopically the most noteworthy feature of the granite in this area is the very small amount of plagioclase present, which entirely fails in some of the thin sections. When present, the plagioclase individuals show broad twinning bands having extinction angles near that of oligoclase. Micro-

cline is a constant constituent, and, though somewhat variable, it may equal in amount the orthoclase. Intergrowths of orthoclase with a second feldspar as microperthite are fairly characteristic. Simultaneous crystallization of the quartz and a part of the feldspar is clearly indicated in micrographic intergrowths of the two minerals, and in the development of the micropoikilitic structure in the potash feldspars. The drop-like inclusions in the feldspar consist of quartz and other feldspar species, principally plagioclase. The feldspars are partially clouded from irregular patchy areas of alteration to minute scales of muscovite and kaolin. Carlsbad twinning is not uncommon among the feldspars. Biotite is in irregular shreds of brown color and strong pleochroism, and in many of the sections it is extensively altered to chlorite. Occasional shreds of muscovite are intergrown with the biotite. Zircon inclusions are somewhat common to the three principal constituents, feldspar, quartz, and biotite. The effects of dynamic forces are manifested in the thin sections by peripheral shattering and recrystallization, and in strained shadows in the principal minerals, quartz and feldspar. Megascopically the arrangement of the minerals along approximately parallel lines is manifested in the development of a thinly schistose structure.

The granite areas farther north in Warren county bear no resemblance in the hand specimens of the rocks to the Raleigh and Greystone granites, though they differ only slightly in mineralogy. In one exposure near Warren Plains biotite entirely fails, and muscovite is substituted. To the north of this locality biotite again assumes the rôle of principal accessory with some muscovite present, and the granite has abundant garnets scattered through it.

The granite of the Louisburg area in Franklin county resembles somewhat that of the Greystone quarries in the hand specimens, except that the former is entirely massive. Plagioclase occurs only sparingly in the granite of the Louisburg area, and microcline and microperthite entirely fail. In other essentials the granite from the two areas is similar. Over parts of the Louisburg area as well as at Greystone a slight porphyritic tendency is indicated in the rock.

THE MAIN GRANITE BELT.

GENERAL CHARACTERS.

This belt is an irregular one in width, occupying the central part of the Carolina Piedmont region, and extending from near the Virginia line in Person county, North Carolina, in a southwest direction across the state into Mecklenburg and Gaston counties, along the South Carolina line. The whole or a part of a dozen counties are included within the limits of this belt. Granite, either massive or schistose in structure, forms the principal rock type over the belt.

Texturally two distinct phases of the granite are developed, an even-granular and a porphyritic granite, both of which have wide distribution. With the single exception discussed on p. 381, the two texturally unlike rocks represent phases of the same granite mass. In all other essentials the normal and the porphyritic granites are closely similar.

Over many parts of the belt the granite manifests some evidence of the effects of intense dynamic forces, in many instances resulting in the partial or complete development of a secondary schistose structure. In thin sections of the rock from those areas in which the granite megascopically appears entirely massive, evidence more or less pronounced of pressure-metamorphism is shown.

The rocks are usually colored some shade of gray, light or dark, in accordance with the proportion of the ferromagnesian mineral present. In some a pronounced pink prevails, and the biotite, which is in very small amount, is not noticeable in the rock. Hardly without exception, the rocks are biotite granites, containing in several places additional hornblende, which is the principal accessory in the granite of several areas in Mecklenburg county, although biotite does not entirely fail in these. Muscovite as a primary constituent is sparingly developed, in a few localities, in association with biotite.

Microscopically the granites are essentially the same in mineral composition as those described above and to the east of this belt. Plagioclase feldspar is a nearly constant constituent, though subject to some variation. At times it exceeds the potash feldspar in amount, and it does not entirely fail in but one or two of the thin sections. Optically it corresponds to a very acid plagioclase, albite or oligoclase, or both. Orthoclase and microcline are both usually present

in the sections, oftentimes in nearly equal proportions, though the microcline is subject to considerable variation. Simultaneous crystallization of the quartz and a part of the feldspar is usually indicated in the distributed areas of micrographic intergrowths of the two minerals and in the development of micropoikilitic structure in some of the feldspars, the inclusions consisting largely of quartz and plagioclase. The usual accessory minerals common to granite are noted in the thin sections of the rocks.

The porphyritic granites have been previously described on p. 378, and it is only necessary here to again emphasize the fact that they are in every case biotite-bearing without hornblende, and are the equivalents in mineral composition of the even-granular granites. Three areas, representing different types of the normal granites, are separately described below. These are: the Dunn's Mountain area in Rowan county; the Mooresville area in Iredell county; and the occurrence of hornblende granite in Mecklenburg county to the north and the south of Charlotte.

LITHOLOGICAL CHARACTERS.

The Dunn's Mountain area.—This is a granite ridge twelve to fourteen miles long, having a general northeast-southwest trend and located a few miles southeast of Salisbury. Numerous quarries have been worked over many parts of the ridge which afford excellent opportunity for obtaining fresh specimens of the rock. Two distinct types of the rock are recognized; (*a*) a very light gray, nearly white, and (*b*) a pronounced pink. The two are intimately associated. They have the same mineral composition and texture, and are apparently phases or differently colored portions of the same rock-mass. The texture is medium even-granular and is fairly uniform. Dynamic metamorphism has manifested itself over all parts of the ridge in a faintly marked schistose structure, and on the Josey-Bogers places three miles southwest of the village of Faith the rock is completely thinly schistose. Over the north slope of Dunn's Mountain proper pronounced shear zones of the crushed and laminated rock, narrow in width, are developed in the granite mass, striking N. 55°–70° E. The rock surfaces are slickensided, accompanied by considerable epidotization.

The component minerals are quartz, orthoclase, microcline, at times microperthite, abundant plagioclase, a little biotite, magnetite, chlorite, epidote, titanite, rutile, and occasional garnet. The granite is largely a mixture of feldspar and quartz, with scant biotite as the third principal component. One of the most striking features in the mineral composition of the rock is its poverty in the ferromagnesian mineral and the excessive plagioclase, which latter constituent exceeds the potash feldspars in all the thin sections examined. Plagioclase is in large, stout, rudely prismatic forms, polysynthetically twinned, and corresponds in optical properties to albite and very acid oligoclase. Both orthoclase and microcline occur, the latter very variable in quantity, being reduced to one or two grains in some sections and in fairly good proportion in others. Microperthite is distributed in small amount through some of the sections. Carlsbad twinning is observed, but it is not so frequent as in some of the granites from other localities in the state. In the pink phase of the rock the feldspars are usually filled with closely crowded dust-like particles of a reddish-brown color, which probably represent some form of iron oxide. Biotite, when present in the thin sections, is of the usual kind, and is distributed through the rock in small, very irregular shreds, altered largely to chlorite. Quartz occupies well-defined areas between the larger feldspars, forming an aggregate of interlocking fine grains, in which feldspar may or may not appear.

Crushing and recrystallization from the action of intense dynamic forces are strongly emphasized in all of the thin sections. Finer mosaics of quartz and feldspar border the larger individuals of the two minerals and fill the interspaces. The larger laths of plagioclase are fractured and broken, and in many instances curved and bent, with irregular fractures and strained shadows common to the other essential components.

The Mooresville area.—The porphyritic granite of the Mooresville area has been previously described on pp. 380 and 381. Attention is here directed to the even-granular granite, which is a very fine textured rock of dark gray color. It is strongly contrasted with that of the Dunn's Mountain area described above. Orthoclase and microcline are in nearly equal amount. Unlike the other areas, plagioclase is very sparingly present, not more than a few grains

being observed in any one of the sections. Some microperthite occurs. Biotite of deep brown color and strong pleochroism is uniformly distributed in large amount through the sections, altered principally to chlorite, a colorless mica, and occasional epidote. Areas of micrographic structure are abundantly distributed through some of the sections, clearly indicating the overlapping of the periods of formation of the quartz and feldspar. Pleochroic titanite in crystals and grains is quite freely developed in one of the sections. Inclusions of apatite and zircon are fairly constant.

The Mecklenburg county areas.—Biotite-bearing hornblende granite occurs one mile east of Davidson in the extreme northern part of the county, and again five to six miles south of Charlotte in the extreme southern part of the county. Hand specimens of these granites are entirely different from, and bear no resemblance whatever to, those of the types previously described. They are of medium texture and gray color, and in the locality south of Charlotte a few bowlders have been worked off for monuments. Much plagioclase is present in association with the potash feldspar. Compact hornblende with strong cleavage development is the principal ferromagnesian mineral present. It is accompanied by more or less biotite of the usual kind, which varies greatly in amount.

The granite to the east of Davidson contains large lath-shaped crystals of the hornblende distributed through it, which measure in extreme cases as much as one and a half inches in length. All gradations in the size of the hornblende individuals down to the smallest grains occur. Chlorite is one of the chief alteration products of the ferromagnesian constituent. Much titaniferous magnetite occurs along with some of the usual minor accessories.

THE WESTERN PIEDMONT GNEISS AND GRANITE BELT.

GENERAL CHARACTERS.

The principal rocks of this belt are gneisses of variable mineral composition. A residual of biotite granite-gneiss, closely resembling in the hand specimens and in mineral composition the well-known Lithonia area of granite-gneiss in Georgia,[1] occurs in Alexander

[1] "Granites and Gneisses of Georgia," *Bulletin No. 9–A*, Geological Survey of Georgia, 1902, pp. 125 ff.

county near Hiddenite. Large areas of biotite granite of medium to coarse texture are located in the northern part of the belt. The Mount Airy area in Surry county, near the Virginia line, may be taken as the type.

LITHOLOGICAL CHARACTERS.

The Mount Airy granite area.—Quarries are worked one and a half miles north of the town of Mount Airy, on a ridge slope of continuously exposed granite. In mineral composition the Mount Airy granite does not differ essentially from some of the types already described, though hand specimens of the rock bear little or no resemblance to each other. The usual granitic minerals are noted, such as quartz, orthoclase, microcline, plagioclase, biotite, muscovite, zircon, apatite, epidote, chlorite, and magnetite. In addition to these, several grains of allanite have been noted in one of the thin sections. Orthoclase is in excess of the microline in all of the sections examined, accompanied by a larger proportion of finely striated acid plagioclase. Zonal growth and Carlsbad twins are beautifully developed in some of the feldspars. Biotite of brown color and strong pleochroism is the principal accessory, and is altered into chlorite, a colorless mica, and some epidote. Much secondary muscovite derived from the alteration of the feldspar and biotite is present. The large individuals of quartz and feldspar indicate peripheral shattering in finer-grained mosaics of the two minerals filling the interstices.

GRANITES OF THE APPALACHIAN MOUNTAIN REGION.

GENERAL CHARACTERS.

Areas of granite and granite-gneiss resembling essentially in mineral composition some of the granite types described above are known over parts of the mountain region of the state. Those of the extreme northwest part of the state have recently been mapped and described by Keith.[1] Since, with perhaps a single exception, those of the other parts of the mountain region are not unlike certain types already described in this paper, only one type is of special interest here, namely, unakite, which occurs in the vicinity of Hot Springs,

[1] *Geologic Atlas of the United States*, "Cranberry Folio, North Carolina–Tennessee." U. S. Geological Survey, 1903.

Madison county, North Carolina, and the contiguous part of Cocke county, Tennessee.

LITHOLOGICAL CHARACTERS.

The Unakite area.—The unakite area in Madison county, North Carolina, and Cocke county, Tennessee, is the type locality first described by Bradley in 1874. I quote in full Bradley's description:[1]

This name [Unakite] is proposed for a member of the granitic series, from the Great Smoky Mountains, a portion of the Unaka range of the Blue Ridge, which range forms the boundary between Tennessee and North Carolina. The specimens thus far seen are from the slopes of the peaks known as "The Bluff," "Walnut Mountain," and "Max's Patch," Cocke county, Tenn., and Madison county, N. C. The rock is said to occur also in Yancey county, N. C., but in a comparatively inaccessible region.

The character relied upon for the separation of the species is the constant replacement of the *mica* of common granite, or the *hornblende* of syenite, by epidote. The amount of this ingredient present is quite variable, in some cases even exceeding one-half of the whole mass. The feldspar present is orthoclase, of various shades of pink, forming from one-fourth to perhaps one-third of the whole. The quartz is mainly white, but occasionally smoky; its isolated portions form but a small part, say one-fourth, of the mass; it is veined in structure, but this is probably not a constant character. Small grains of magnetite are scattered through the rock, but not so thickly as in many granites. No other ingredients have as yet been detected. Mr. G. W. Hawes has determined the specific gravity at 2.79. The rock is very compact and takes a high polish, and will doubtless prove to be a valuable material for ornamental architecture.

The deep weathering of all the rocks of the Southern Appalachians has caused the covering of most of these mountain slopes with deep beds of débris, which conceal most of the solid outcrops; and the dimensions of the bodies of uanakyte are therefore as yet unknown. Apparently forming part of the same series, there are heavy beds of specular iron ore; and the whole series is referred with little doubt to Archaean age.

The outcrops of the granite over the surface, as traversed by me, indicate an area of about twenty-four square miles, lying mostly in Madison county, North Carolina, beginning about five miles southwest of Hot Springs. Further detailed work will probably extend the boundaries of the area considerably beyond those mentioned here.

Two types of the granite occur in the area, both of which contain epidote. The bulk of the granite or main body of the rock is a dark

[1] *American Journal of Science*, Vol. CVII (1874), pp. 519, 520.

pinkish-green epidote granite of medium-coarse texture and fairly schistose or foliated in structure. This is not the unakite proper, but may be properly designated the epidote-bearing rock. It varies from a typical granite in which quartz is present in the usual amount to a nearly quartzless rock of the same color and texture. The unakite proper is a coarse-textured rock composed of yellow-green epidote, dull pink or red feldspar, and quartz. It is not entirely uniform in color and composition, but it grades into a highly feldspathic rock of pink color on the one hand, and an epidotic rock of yellowish-green color on the other, with still a third gradation observed into pure quartz.

Thin sections of the epidote-bearing granite show the principal minerals, quartz, orthoclase, and microcline, in about equal proportion, a little plagioclase, biotite, epidote, chlorite, rutile, zircon, apatite, magnetite, pyrite, and kaolin. The epidote distributed through the sections is wholly a secondary product derived from the interaction of the biotite and feldspar. It occurs in the form of minute microscopic granules thickly crowded together, in many cases lying next to the biotite. The mass of granules, when forming an area large enough to be visible megascopically, appears as a single large epidote individual rather than as separate microscopic granules. Besides epidote, the feldspars are altered to a colorless mica, and in some instances the original mineral is completely obscured by the alteration products. At times the feldspars are much fractured and broken, the fissures of which are now filled with another mineral substance. Sometimes alteration has progressed along the lines of fracture in the feldspar, and patches and stringers of deep-green mica line them. Thread-like filaments of rutile, broken into minute segments, are crowded together in the quartz anhedra. Some peripheral shattering from pressure-metamorphism is indicated in narrow zones of fine-grained mosaics of quartz and feldspar partially surrounding these two minerals. Strained shadows and fractures are common to both the larger quartz and feldspar grains.

The principal difference microscopically between the unakite and the epidote-bearing rock is that of extreme epidotization of the former, further marked by the absence, in those sections studied, of both plagioclase and ferromagnesian minerals, identified as such.

Since both of these minerals are present in the epidote-bearing rock, their absence in the unakite is very likely due to extreme epidotization of the unakite, completely altering both the mica and the plagioclase in case these were originally present. That mica or some ferro-magnesian constituent was originally present in the unakite it seems necessary to assume in order to meet the requisite conditions of formation of so large a quantity of epidote.

The principal component minerals in the unakite are quartz, orthoclase, epidote, rutile, titaniferous iron oxide, and secondary muscovite, kaolin, and leucoxene. Rutile is contained in the quartz anhedra as inclusions of hair-like filaments. The orthoclase has a pronounced pink color in the hand specimens which disappears in the thin sections. Here, as in the epidote-bearing rock, conclusive evidence is furnished of the wholly secondary nature of the epidote. Its largest occurrence is in the replacement of the feldspar individuals in the form of a complete mass of microscopic granules, entirely obscuring in many cases the feldspar substance, but preserving the outline of the latter in a more or less perfect manner. The granular masses of epidote appear in the hand specimens as single large epidote anhedra. Other feldspar individuals show patchy areas and scattered granules of epidote over their surfaces. Still a third occurrence of the epidote is in irregular broken bands or stringers, following the network of fractures in both the feldspar and the quartz. In some cases these stringers ramify outward from the granular masses of epidote, replacing the feldspar. Again the granular masses often show irregular margins traced outward from the more compact mass into scattered granules of epidote. All gradations between these occurrences of the epidote are traced. Very little of the feldspar is entirely free from epidotization.

Some peripheral shattering accompanied by much fracturing of, and strained shadows in, the quartz and feldspar, indicating the effects of dynamic forces, characterizes to some degree all of the thin sections.

It seemed quite conclusive, from the different exposures studied of the unakite in its relations to the inclosing epidote-bearing granite, that the unakite is of distinct vein character which can be referred

very likely to the segregation type.[1] It does not exist in quantity large enough to be worked over any part of the area traversed by me; hence it has only scientific interest.

STRUCTURAL FEATURES OF THE GRANITES.

MEGASCOPIC STRUCTURES.

Joints.—With possibly one or two exceptions, the Carolina granites are characterized by a strong development of the jointed structure, the planes of which break the rock into polygonal blocks of different sizes, as indicated in Fig. 4. The most noteworthy exception is that of the extensive granite area near Mount Airy, in which no visible jointing is apparent. Careful measurements of the joint-planes were made in all the granite openings visited in the state, and the results can be summarized as follows: Those joints whose planes lie in the northeast and the northwest quadrants respectively, and composing the major jointing; and two minor sets whose planes strike east-west and north-south. In the northeast and the northwest quadrants the limits of variation in the strike of the joint-planes are N. 10° E. or W., to N. 80° E. or W. Out of the total number of joint-planes measured fifty-six lie in the northeast quadrant and forty-five in the northwest quadrant; while nineteen strike in a north-south direction, as against sixteen having an east-west strike.

Slickensides.—As a rule, the joint-planes show smooth, more or less polished and striated surfaces, indicating considerable movement in the rocks since the formation of the joints. Striæ are developed in a thin coating of yellow to yellowish-green mineral substance, derived from certain minerals in the granite and produced by the rubbing together of the two sides along the plane.

Schistosity.—Between the perfectly schistose granites (granite-gneisses) and the perfectly massive granites, nearly all gradations in

[1] Since this paper was written, PHALEN ("A New Occurrence of Unakite," *Smithsonian Miscellaneous Collections*, Vol. XLV (1904), pp. 306–16) has published a preliminary paper on the occurrence and petrography of unakite at Milams Gap in Virginia. The rock in which the unakite occurs in the Virginia locality is reported by the author to be hypersthene akerite. The epidote of the unakite is secondary, replacing pyroxene and feldspar, both plagioclase and orthoclase. The author believes the unakite has originated from the akerite by hydrometamorphism, aided perhaps by dynamic disturbances.

schistose structure are shown. Not in the same mass, however; for not in a single instance has such been observed. Whether the entirely schistose structure is more or less sharply and completely separated from the massive, or whether they grade from one into the other, it is impossible to say, owing largely to the lack of sufficient exposures of the rocks. Even in most of those granites which megascopically

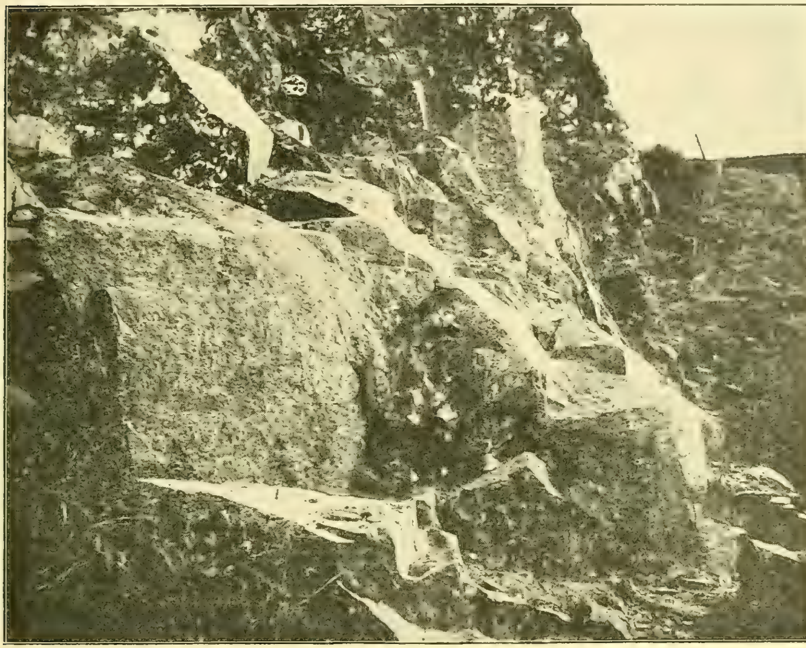

FIG. 4.—Vertical jointing in granite. City of Charlotte quarry, North Carolina.

appear massive, more or less evidence is shown in the thin sections of the effects of dynamic forces, in peripheral shattering or granulation, and in strained shadows and fractures in the quartz and the feldspar. In such cases no semblance of rearrangement of the mineral components along certain definite lines appears.

Basic inclusions.—The granite in many of the quarries contains inclusions of basic segregations which were formed from the cooling magma. These are invariably of darker color and finer grain than the inclosing granite, and are entirely massive. Sections from them resemble closely the inclosing granites in mineral composition, except

that biotite is greatly in excess, while quartz may be somewhat diminished in quantity. It frequently requires the closest examination, megascopically, to detect more of the minerals than the dark ferromagnesian components, except in a few cases where an occasional porphyritically developed feldspar has formed, so fine-grained and very dark in color are the schlieren.

Their distribution in the granites is subject to much variation. From some quarries they are entirely absent, in others they are developed only occasionally, and in others still they are so abundant as to exclude the rock from use in certain higher grades of work. Variation in size is from a fraction of an inch to more than a dozen inches across. Irregularity of outline is usually characteristic of them, variation being from roughly oval-shaped and round to greatly elongated areas, one of whose diameters is several times that of the second.

MICROSCOPIC STRUCTURES.

Peripheral shattering or granulation and recrystallization has already been mentioned. It is only necessary here to call attention briefly to two fairly constant microstructures in the granites, observed in similar rocks elsewhere, namely, granophyric and micropoikilitic.

Granophyric structure.—Granophyric intergrowths of feldspar and quartz are either sparingly or abundantly developed in most of the thin sections examined of the Carolina granites. They display the usual form and development observed in granites in general. So far as it was possible to determine, the intergrown feldspar may be either of the potash or plagioclase species. The areas may be inclosed by the larger feldspar individuals, or they may be formed at or near the contact between the larger feldspar and quartz grains. Their character clearly indicates simultaneous crystallization of the two minerals—an overlapping in the period of formation of the feldspar and quartz. This conclusion finds added confirmation in the micropoikilitic structure described next below.

Micropoikilitic structure.[1]—In thin sections of the granites from both North Carolina and Georgia, certain of the large feldspar

[1] G. H. Williams, "On the Use of the Terms Poikilitic and Micropoikilitic in Petrography," Journal of Geology, Vol. I (1893), pp. 179 ff. This paper contains numerous references to published accounts of this structure.

individuals are frequently filled with crystals, or grains of other minerals, arranged without reference to one another or to their host. Hardly without exception, the inclosing mineral is a potash feldspar, and the included minerals are quartz and plagioclase, with an occasional shred of biotite. In the phenocrysts of the porphyritic granites this order is frequently reversed, and biotite is often inclosed in largest amount. Variation is from several scattered included grains in the feldspar to hosts fairly filled with the inclusions. The inclosed quartz grains are rounded in outline, drop-like in form, while the striated plagioclase may vary from similarly rounded grains to lath-shaped forms.

Because of its occurrence in devitrified glasses, Williams[1] ascribed in some cases a secondary origin to the very abundant micropoikilitic structure in the ancient acid lavas of South Mountain, Pennsylvania, and Maryland. There is no evidence for regarding the structure in the Carolina and Georgia granites of other than primary origin—a fact which aids, as I interpret it, in formulating the order of separation of the feldspars and quartz from the magma. When viewed in connection with the granophyric structure described above, the two microstructures furnish conclusive evidence of the overlapping in the period of crystallization in the potash and plagioclase feldspars and the quartz in the southern granites. A tendency was noted in many of these sections toward maximum development of the two structures in the same thin section. This seeming association was by no means a constant feature, for many sections in which granophyric intergrowths were present indicated the entire absence of the micropoikilitic structure.

INTERSECTING DIKES AND VEINS.

Genetically the intersecting materials are of two kinds, true dikes and true veins. These contrast quite strongly in some instances, and in all cases they show differences to some degree in both texture and composition.

BASIC IGNEOUS DIKES.

Dikes of basic igneous rocks, principally diabase or its altered form, were observed penetrating the granites in most of the important areas in the state. A majority of these were noted from surface

[1] G. H. Williams, *American Journal of Science,* Vol. XLIV (1892, 3d S.), p. 482.

exposures of the rocks, and hence more or less deeply decayed, while many of them were exposed in the quarry openings, which afford excellent opportunity for observing their relations to certain structural features of the granite discussed below (Fig. 5). In several quarries in widely separated parts of the state a series of some half-dozen or more dikes were observed. Where exposed in the quarries,

FIG. 5.—Dike of diabase penetrating granite in the city of Charlotte granite quarry, North Carolina. Part of a second dike is visible in the extreme left of the view.

none of the dikes exceed fifty feet across, and usually they are less than four feet.

Lithologically two types are indicated. The first is usually an unaltered massive diabase, the thin sections of which show under the microscope the essential minerals and structure of diabase. The pyroxene in this type may be considerably altered in some of the dikes, and in hand specimens the rock presents a rather pronounced greenish hue, resulting from the alteration. The second type is more or less completely thinly schistose, and is largely composed of horn-

blende, some feldspar and quartz, and may contain much additional pyrite. The rock is a typical amphibolite derived from an original diabase or diorite or both.

The structural relations of the dikes to each other and to the inclosing granites clearly indicate at least two different periods of penetration of the granites by the basic rocks, and therefore different ages for the dikes. More or less complete evidence of schistose structure in the inclosing granites is sometimes noted in those cases where cut by dikes of similar structure. I take it that the period of intrusion of the dike antedates that of the dynamic disturbance inducing schistosity into both dike and granite alike. In those cases where the dike rock remains massive and the inclosing granite shows evidence of schistose structure, the reasonable conclusion is that the basic dike material penetrated the granite after the period of dynamic disturbance closed.

GRANITE DIKES

True granite dikes of normal composition and usually fine texture are numerous in certain areas, but only in one or two instances have they been observed penetrating the granite masses. In the main granite belt of the Piedmont region dikes of this character are quite frequent, penetrating the surrounding rocks, and they must be regarded as apophyses from the granite massifs (Fig. 6). As a rule, they vary only a few degrees from the vertical; are irregular in outline; fine-grained in texture; composed of light to pink feldspar and quartz, with subordinate amount of mica, which may entirely fail at times; and they range from a few inches to several feet in width.

PEGMATITE AND APLITE.

Pegmatites are present in large numbers in some quarries and entirely fail in others. As a rule, they do not attain very large size, but are narrow, apparently deep-seated, and of aqueo-igneous origin. Others are limited in extent, surrounded entirely by the granite, marking in such cases true veins of segregation. Texture and composition of the two are identical. They are chracterized by the usual coarse crystallizations of feldspar and quartz, with subordinate stout, platy, black biotite. The feldspar may be pink or white, showing

good cleavage development, and twinning on the Carlsbad law. Feldspar is the most abundant constituent, composed of microcline and orthoclase, with little plagioclase; quartz frequently occurring in very small amount. Muscovite has been observed occasionally; and tourmaline, garnet, and the rarer minerals sometimes associated with pegmatites, are strikingly absent.

FIG. 6.—Granite dike west of Salisbury, North Carolina.

In the Raleigh city quarries where the only true aplite has been observed, the aplite and pegmatite are associated as banded aplite-pegmatite, the aplite being in contact with the pegmatite on one side and the inclosing granite on the other. They are very light-colored rocks, containing but little biotite; are fine-grained; and are only a few inches across. Orthoclase, microcline, very little plagioclase, microperthite, quartz, biotite, muscovite, chlorite, rutile, magnetite, and kaolin appear in thin section. Microscopically they are potash aplites.

QUARTZ VEINS.

Quartz veins of small dimensions cut the granite in a number of quarries; usually, in the ones where pegmatitic intrusions are strongly developed. They are not numerous in any of the openings, and, as a rule, they will not measure more than a few inches across. Veins of quartz of considerable dimensions are numerous over the crystalline

FIG. 7.—Stone Mountain, Wilkes county, North Carolina. A granite residual. Several others are shown in the distance on the extreme left of the view.

area of the state, and they can be readily traced over the surface for considerable distances by partially disintegrated outcrops and abundant angular fragments which litter the surface.

RELATIONS BETWEEN THE JOINTS IN THE GRANITE AND THE DIKES OF BASIC ROCK.

Referring to the direction in the strike of joints discussed on p. 23, it will be observed that the planes of most of the joints lie in the northeast and the northwest quadrants, respectively. Likewise careful measurement and tabulation of the dikes of basic rocks show that the

direction of strike of most of them is in the same quadrants as the strike of the joints. Furthermore, in nearly every quarry exposing dikes of basic igneous rocks the strike of the dikes and that of one set of joints were coincident, probably indicating that for the areas mentioned the jointing has exercised some influence in the cutting direction of the dikes.

Not only is this true of the dikes penetrating the granites, but it is equally true of the Triassic sandstone belt, where coincidence in strike of the diabase dikes and that of jointing in the sandstone is very strikingly shown.

Careful measurements in the strike of the joints and the dikes were made in the numerous openings over the sandstone belt, which can be summarized as follows:[1] Variation in major jointing is from N.15°–60° W. to N. 20°–60° E., with minor sets noted in some openings striking N.-S. and E.-W. Likewise, variation in strike of the dikes is from N. 20°–60° W. to N. 20° E., with a few striking N.-S. In every opening the strike of the dikes and that of the joints for a given direction was found to be coincident.

Whether this will apply in general to those dikes beyond the limits of the fresh rock exposures it is not possible to say at present, as the jointing is entirely obscured by the deep residual decay covering the fresh rocks.

AGE-RELATIONS OF THE DIKES OF BASIC IGNEOUS ROCKS.

As noted above in the basic dikes penetrating the crystalline rocks, strongly contrasted structural differences in the dike rocks obtain. Many of them are entirely massive and unaltered, bearing little or no evidence of pressure-metamorphism, while a large proportion of them are completely schistose, and are otherwise mashed and closely jointed. The ferromagnesian constituent in the latter is usually partially or completely altered. Both classes of the dikes often penetrate original massive igneous rocks that are now more or less schistose in structure. These facts afford a strong and sufficient basis for regarding the basic rocks of the dikes of different periods of intrusion, and therefore, of different age. The massive dikes penetrating the more or less schistose rocks must postdate in age the period of

[1] Data kindly furnished by Mr. F. B. Laney.

disturbance inducing the schistose structure in the inclosing rocks. Likewise the schistose dikes were intruded at an earlier period and prior to the metamorphism of the inclosing rocks, for the field evidence indicates that the schistose structure in the dike and the inclosing rock is the result of the same forces. Until the age of the inclosing rocks is definitely determined, that of the more schistose dikes must largely remain conjectural. As stated, the dikes must antedate the period of pressure-metamorphism affecting the inclosing rocks, for both dike and inclosing rock are similarly affected.

The sandstones of Triassic age occupying the marginal position along the eastern border of the Piedmont region, are cut by a system of typical massive, unaltered, diabase dikes. The dikes conform, as a rule, to northeast and northwest directions, and are coincident in strike with that of the joints in the sandstones for these directions. Nowhere have the dikes been observed to cut rocks younger than the sandstone, and their age is accordingly definitely fixed as middle Mesozoic. They are correlated with flows of the same composition and age in New Jersey, New York, and the Connecticut Valley region, and with similar dikes in Virginia and Georgia to the north and south of the Carolina area.

The dikes of the Carolina sandstone belt are traced into the neighboring crystalline rocks of the Plateau region, where they have wide distribution. Beyond the limits of the sandstone belt, in the crystalline areas penetrated by the dikes, close similarity in texture, structure, and composition of the massive dikes obtains, and their relations to the inclosing crystalline rocks make it reasonably certain that they are of the same age as those penetrating the Triassic sandstones.

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GEOLOGICAL NOTES ON THE VICINITY OF BANFF, ALBERTA.

Banff, the easternmost of the resorts established by the Canadian Pacific Railroad in the mountains of the Northwest, lies a little east of the axis of the Rocky Mountain range, on the Bow River, at an altitude of 4,521 feet. The surrounding mountains rise to heights of 8,000 to 10,000 feet and upward.

Structure of the mountains.—The Rocky Mountains in Alberta contrast with the same range in the United States in that folding and overthrust faulting are their predominant features. Their structure closely resembles that of the southern Appalachians, contrasting strongly with the Basin type where normal faulting is the rule.

In Alberta parallel ridges of folded Carbonic limestones are the prevailing features. These are underlain by Cambrian sandstones, and overlain by coal-bearing Cretaceous sandstones. About Banff the general trend of the ridges is northwest-southeast.

Drainage.—The normal drainage of the region is similar to that often noted in the Appalachian region; the channels being established either along the strike of some soft layer, or cutting across the ridges at right angles to the strike. In such a region stream robbery is common, and one river will, at an advanced stage of adjustment, present a series of right-angled turns, wind-gaps often indicating former channels.

Glaciation.—The Canadian Rockies have been heavily glaciated at a comparatively recent date. The glacial action appears to have been that of very large valley glaciers, rather than of the continental ice-sheet. Local moraines are common, and the larger valleys are bordered by glacial terraces.

The drainage in the vicinity of Banff presents several interesting features. The Bow River, after flowing southwest along the strike of the Cambrian sandstones, turns abruptly northeast, cutting a gap in the Sawback, Vermilion, and Cascade ranges (see map, Fig. 1). It then turns southeast again, flowing along the strike of a Cretaceous

FIG. 1.—Topographic map of the Rocky Mountains near Banff. Reduced from Canadian Geological Survey.

infold. At Banff the Bow River is joined by the Spray River from the southeast and by the Cascade River from the northwest. Lake Minnewauka outlets westward into the Cascade River, its eastern end leading through a wind-gap to the Ghost River.

The Bow Valley about Banff is drift-filled. Westward from the station its course is through gravel, largely stratified (Fig. 2). At the

FIG. 2.—Still waters and alluvial deposits of the Upper Bow River above Banff; Mount Edith in the distance.

station the river turns abruptly southeast, cutting a little canyon along the strike of Carbonic shale and forming the Bow Falls. At its junction with the Spray it again enters drift and again turns northeast. There is here presented the abnormal feature of a water-fall along the strike, followed by quiet water when the course is at right angles to strike and up dip.

Forty-mile Creek flows southeast along the strike between Vermilion and Sawback ranges. It cuts across a gap in Vermilion

range and cuts off the end of Cascade Mountain. As it enters the Bow Valley it turns abruptly west, flowing over drift for a mile and a half, and emptying into Vermilion Lake.

These various abnormalities are the result of two distinct causes: first, adjustment to the soft Cretaceous infold of the lower Bow Valley; second, glaciation.

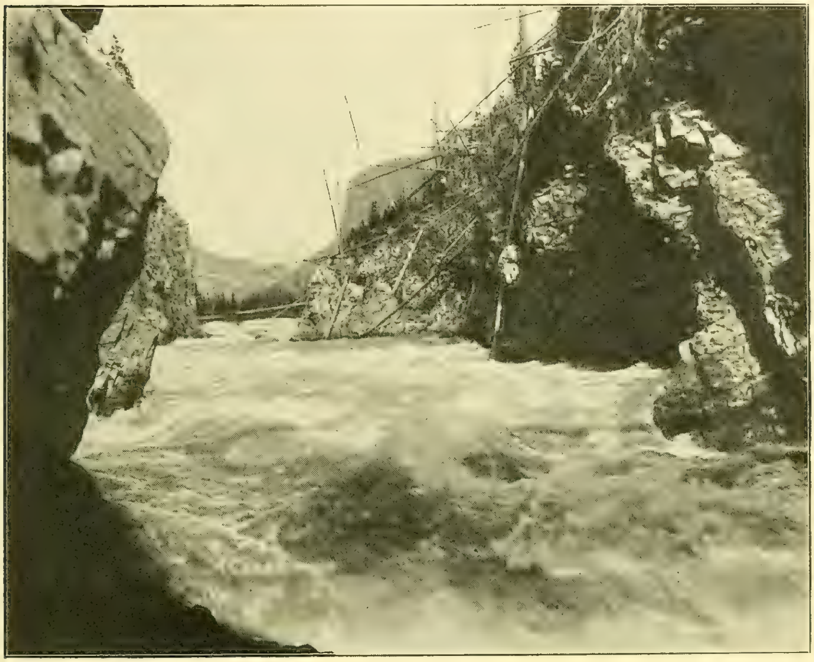

FIG. 3.—Devil's Canyon; a postglacial gorge of the Cascade River.

Lake Minnewauka (Devil's Lake) is a body of water twelve miles long and about half a mile wide. Its sides are precipitous, except close to the water's edge where glacial gravels are found. Alluvial cones occur, projecting into the lake. As noted by Dawson in 1885,[1] this lake basin presents every appearance of having formerly been a river valley. Its eastern end is now filled with drift, talus, and alluvial cones, but its level floor and steep sides extend to Ghost River on the east. Dawson, in the report cited, suggests that this was the

[1] *Report B*, Geological Survey of Canada, 1885, p. 141.

preglacial course of the Bow River. If this were the case, a drift-dam, or indications of an ice-dam, should be found, and the valley beneath the drift should present older features in the preglacial than in the present Bow Valley.

An investigation of the western end of the Lake Minnewauka disclosed hills of morainic aspect, evidently deposited at the junction of an ice-lobe descending the Cascade Valley with one coming from the Minnewauka Valley. Westward from these morainic hills is an overwash plain which descends westward and southeastward to form the upper terrace of the Cascade River. Lake Minnewauka is held up by this moraine, and its existence as a lake undoubtedly dates from the time of retreat of the ice. But that this dam could have diverted the Bow River is not possible. The outlet of Lake Minnewauka flows through drift for about a mile; it then joins the Cascade River, and together they flow through a postglacial gorge cut in Carbonic limestone. This gorge is known as the Devil's Canyon. The surface of this limestone is drift-covered, and the top of the gorge undoubtedly represents the height of the valley floor before the ice-invasion, also the amount eroded by the ice. This level is 5,000 feet. The limestone cut by the Devil's Canyon extends in a low ridge for more than a mile and blocks any considerable outlet or inlet of the Minnewauka Valley. Any river flowing in or out of this valley in preglacial times must have had its floor above 5,000 feet.

Five miles southwest of the lake the Bow River flows mainly over gravel. The Cretaceous beds are occasionally exposed, but the valley bottom is mainly in drift. The valley floor at this point is 4,350 feet, and the preglacial river in this valley could not have been higher. It therefore follows that no preglacial river could have flowed from the Bow to Lake Minnewauka Valley.

Moreover the lower Bow Valley (below the junction with Cascade River) is older physiographically than the Lake Minnewauka Valley. The sides are less precipitous, the cross-section, though steep sided, more nearly U-shaped.

In the opinion of the writer, the present drainage at this point is due, not to glacial agencies alone, but to preglacial adjustment to the soft Cretaceous beds. The Minnewauka Valley and the Bow Valley above the junction with Cascade River were probably once

one valley. Stream robbery then took place, owing to the advantage possessed by the present lower course of the Bow, a stream on the Cretaceous beds, over the upper part, the upper Bow-Minnewauka River. This adjustment was preglacial. The Bow was thus drawn away into its southeastward course in preglacial time, and a divide was established at the western end of Minnewauka Valley. A river

FIG. 4.—Bow Valley, from the Banff Springs Hotel; the preglacial course of the Spray River. At the left the Bow is emerging from its postglacial canyon.

continued to occupy this valley, emptying into Ghost River, until obliterated by the ice-invasion. The basin may have been deepened by ice-gouging; at all events, as the ice retreated northward, a lake was formed at its western margin, and an outlet was formed to the west, the eastern end of the gorge being still ice-filled. By the time the ice had retreated altogether, the westward outlet was too well established for a return to the eastward drainage. The present level of the lake is lower than that of Ghost River.

The abnormalities in the vicinity of Banff village appear to be due to glacial agencies only. Forty-mile Creek takes its abrupt westward bend at the point where its old valley is filled by drift. The Bow takes its southward turn around Tunnel Mountain for the same reason, namely, damming of its old valley by drift, its present rapids and fall being postglacial. South of Tunnel Mountain the Bow leaves its gorge and turns into the preglacial valley of the Spray (Fig. 4). The Spray itself has been pushed out of its valley at this point by talus from Mount Rundle.

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GLACIAL AND POST-GLACIAL HISTORY OF THE HUDSON AND CHAMPLAIN VALLEYS.

OUTLINE.

Wave-wrought features in the Hudson Valley.

Fossils in the Hudson Valley and in the lowland west of the Palisade Ridge.

Buried soils.

WESTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.

EASTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.

CHAMPLAIN VALLEY.

East side, Lake Champlain.

West side, Lake Champlain.

Clay plain.

Gravel plateaus and deltas—upper and lower series.

Wave-wrought terraces.

Upper series.

Lower series.

Fossils.

Moraines.

Eskers.

The streams and their valleys.

Fort Edward Valley.

Whitehall-Putnam Station Valley

Submerged Poultney-Mettawee Valley.

Erosion of tributaries to Poultney-Mettawee stream in southern Champlain region.

[*Outline to be concluded.*]

INTRODUCTORY STATEMENT.[1]

THE plans for the investigation the results of which are here presented were first made under the direction of Professor R. D. Salisbury. At the beginning of the actual work, in the absence of Professor Salisbury from the country, the work was pursued under the direction of Professor T. C. Chamberlin, and has been continued under his direction up to the present time. The writer's interest in the subject was first aroused while engaged in detailed mapping of the Pleistocene deposits of the Palisade Ridge of eastern New Jersey in 1893 and 1894, under Professor Salisbury's direction.[2] Subsequently, in the preparation of the Pleistocene maps for the *New York City Folio*[3]

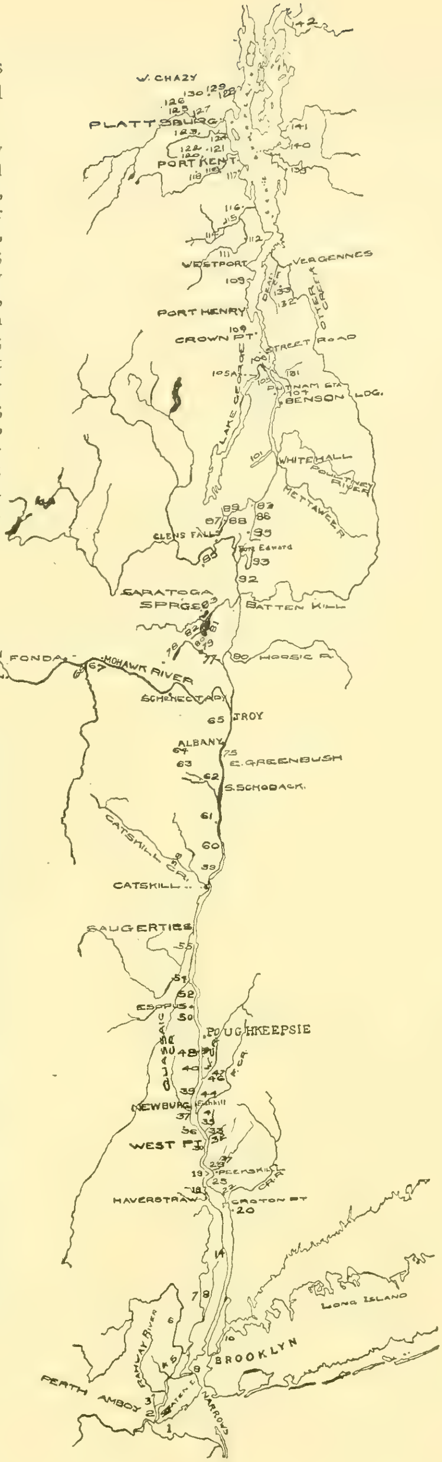
[1] A brief summary of this paper was presented before the Geographic Society of Chicago in March, 1904. An alternative hypothesis bearing on crustal movement entertained at that time has replaced one favored then.

[2] See ROLLIN D. SALISBURY AND CHARLES E. PEET, "Drift Phenomena of the Palisade Ridge," *Annual Report of the State Geologist of New Jersey*, 1893.

[3] See Pleistocene maps of the *New York City Folio*, *U. S. Geological Survey*, by ROLLIN D. SALISBURY, assisted by HENRY B. KUMMEL AND CHARLES E. PEET.

FIG. 1.—Reference map. The numbers refer to places in the following list. On all the maps each place has the same number.

133, Addison; 104, Addison-Rutland County Line; 67, Amsterdam; 27, Annsville; 2, Arthur Kill and Perth Amboy; 59, Athens; 78, Ballston Lake; 82, Ballston Spa; 129, Beekmantown; 111, Bouquet River and Wadham's Mills; 35, Breakneck Mountain; 139, Burlington and the Winooski River; 125, Cadyville; 58, Cairo; 48, Camelot; 44, Carthage Landing and Low Point; 33, Cold Spring and Foundry Brook; 109, Cole's Bay; 36, Cornwall; 60, Coxsackie; 22, Croton Landing; 108, Crown Pt. Center; 126, Dannemorra; 95, Dunham's Basin; 41, Dutchess Junction; 131, East Creek; 10, East River; 4, Elizabeth River; 8, Englewood; 119, Ferrona; 97, Fort Ann; 92, Fort Miller; 33, Foundry Brook and Cold Spring; 55, Glasco; 87, Glen Brook and Glen Lake; 7, Hackensack and Hackensack River; 120, Harkness Station; 30, Highland Falls; 90, Hoosic River delta; 89, Hopkin's Pond; 32, Indian Brook; 88, Jenkins Mills, Queensbury, and Round Pond; 19, Jones' Point; 118, Keeseville; 9, Kill van Kull; 141, La Moille River and West Milton; 83, Lonely Lake; 44, Low Point and Carthage Landing; 140, Mallett's Bay; 80, Maltaville; 40 Marlboro; 77, Mechanicsville; 142, Missisquoi River; 85, Moreau Pond; 127, Morrisonville; 93, Moses Kill; 105, Mount Defiance; 122, Mount Etna; 5, Newark Bay; 61, New Baltimore; 46, New Hamburg and Wappinger Creek; 63, New Scotland; 65, Newtonville; 37, New Windsor; 114 North Branch of Bouquet River and Tower's Forge; 62, Oniskethau, Spraytkill, and South Bethlehem; 20, Ossining (Sing Sing); 6, Passaic River; 2, Perth Amboy and Arthur Kill; 121, Peru; 117, Port Douglas; 88, Queensbury, Round Pond, and Jenkins Mills; 1, Raritan River and Bay; 115, Reber; 54, Rondout; 39, Roseton; 79, Round Lake; 88, Round Pond, Queensbury, and Jenkins Mills; 104, Rutland-Addison County Line; 123, Salmon River and Schuyler's Falls; 81, Saratoga Lake; 68, Schoharie Creek; 123, Schuyler's Falls and Salmon River; 20, Sing Sing (Ossining); 132, Snake Mountain; 101, South Bay; 62, South Bethlehem, Spraytkill and Oniskethau; 124, South Plattsburg; 14, Sparkill Valley; 62, Spraytkill, South Bethlehem, and Oniskethau; 28, State Camp; 71, St. Johnsville; 18, Stony Point; 75, Teller Hill; 106, Ticonderoga; 114, Tower's Forge and North Branch of Bouquet River; 128, Treadwell Bay; 52, Ulster Park; 25, Verplanck's Point; 64, Voorheesville; 111, Wadham's Mills and Bouquet River; 46, Wappinger Creek; 47, Wappinger Falls; 130, West Beekmantown; 50, West Park; 112, Whallonsburg; 116, Willsboro; 139, Winooski River; 3, Woodbridge Creek; 96, Wood Creek; 141, West Milton and La Moille River.



and for the report on the *Glacial Geology of New Jersey*,[1] under Professor Salisbury's guidance, work bearing on the problems here involved was carried out in 1897 and 1901. The main results here presented were in hand before the latter date, and the advance since then has been mainly in determining the crustal movement and in the analysis of facts bearing on the origin of the Hudson water body. To Professor Salisbury the writer is under obligation for the opportunity of detailed study of the Pleistocene formations of New Jersey and adjacent portions of New York, for early training in methods of investigation and mapping of those formations, and for suggestions in the original plans for the work, the results of which are here presented. To Professor Chamberlin the writer is under obligation for assistance with difficulties encountered in this investigation, and for continued inspiration to perseverance in searching out the truth. Neither Professor Chamberlin nor Professor Salisbury is responsible for opinions here expressed or for any failure to arrive at the truth.

GENERAL STATEMENT OF TOPOGRAPHY OF EASTERN NEW YORK AND SOUTHERN NEW ENGLAND.

Southern New England has been described as an upland rising gradually inland from the sea and reaching elevations of 1,500 to 2,000 feet in southern New Hamsphire and Vermont.[2] Above this upland there rise higher elevations such as Mt. Monadnock, and groups of elevations such as the Green Mountains and the White Mountains. Below the upland, valleys have been sunk, a small amount near the sea, but deeper farther inland. These valleys are broad on the soft rocks and narrow on the harder rocks.

Without assuming an identical history, this picture may be transferred to eastern New York, where, as a first approximation to the truth, the country may be pictured as a rolling surface rising inland from the narrows at Long Island and Staten Island. Above this surface there are elevations, such as the Adirondacks and the Green Mountains. Below it there are depressions, such as the Hudson and Champlain Valleys.

[1] See *Glacial Geology of New Jersey*, by ROLLIN D. SALISBURY, assisted by HENRY B. KUMMEL, CHARLES E. PEET, AND GEORGE N. KNAPP (Vol. V of the Final Report of the State Geologist, 1902).

[2] DAVIS, *Physical Geography of Southern New England.*

The Hudson Valley has three natural divisions: (1) the part south of the Highlands from Peekskill to the narrows at Brooklyn; (2) the Highlands from Peekskill north to near Fishkill; and (3) the broader Hudson Valley from near Fishkill to north of Glens Falls.

North of the Hudson Valley is the Champlain Valley, to which two passages lead, one by way of Lake George and the other east of the Lake George pass by way of southern Lake Champlain. The broader Hudson Valley and the Champlain Valley have been considered the northeastward continuation of the Greater Appalachian Valley.

SUB-LACUSTRINE OR SUB-MARINE GLACIAL DEPOSITS IN THE HUDSON AND CHAMPLAIN VALLEYS.

In the bottom of the Hudson and Champlain Valleys there has been built in recent geological times a plain mainly of clay, with margins frequently of gravel and sand.[1] This plain has the form of an old lake-floor or old sea-floor. The clay plain is best seen in the northern part of the Hudson from Catskill north. In the southern part of the valley—from Poughkeepsie south—it is either absent entirely, or is to be seen only in limited areas, and generally covered with gravel and sand. The clay in both the Hudson and Champlain Valleys is laminated, with alternate "fatty" and sandy laminæ having a thickness of one-fifteenth of an inch or more. (See Fig. 2.) The laminæ are sometimes grouped into beds a few inches in thickness, separated by rather prominent lines of parting. In one place ripple marks were seen. (See Fig. 3.) The clay often shows faulting and frequently shows joint structure conspicuously. (See Fig. 2.) It is sometimes contorted. The upper part of the clay is generally yellow in the Hudson Valley and brownish-red in the Champlain Valley. The

[1] The clays and gravels and sands of the Hudson Valley have been described in considerable detail by F. J. H. MERRILL AND HEINRICH RIES in the *Tenth Annual Report of the New York State Geologist*, and by MR. RIES in the *Bulletin of the New York State Museum*, Vol. III, No. 12. The former report was in hand in the field, and while the interpretation placed on these deposits is quite different, the writer wishes here to make general acknowledgment of its aid in his studies. Specific acknowledgment is made in the proper place where this report has been drawn upon for facts beyond the writer's personal observation. The writer also had the aid in the field of the article by S. PRENTISS BALDWIN on "The Pleistocene History of the Champlain Valley," *American Geologist*, Vol. XIII (1894), pp. 170–184.

lower part is blue. Bands and blotches of yellow often occur in the midst of the blue layers in the Hudson Valley. The clay often contains concretions. In thickness the clay varies from a small amount

FIG. 2.—Showing joint structure in the laminated clay of the Hudson Valley.

to 215 feet in the valley of the Hackensack and zero to 243 feet[1] in the Hudson Valley, where it is commonly 80 to 100 feet or more thick. In the Champlain Valley it is known to have a thickness as great as 60 to 75 feet, but is generally thinner than in the Hudson Valley.

[1] H. RIES, *Bulletin N. Y. State Museum*, Vol. III, No. 12, p. 184.

The clay overlies till (Fig. 4), gravel and sand, or rock surfaces, which are frequently striated. It fits into the irregularities of the till, or the stratified gravel and sand which sometimes appears to have the form of kames. In the upper Hudson the underlying stratified sand and gravel often has a high angle of dip, generally southward, but sometimes in other directions. These layers are interpreted as representing deposits made by the ice waters in the standing body of water as the ice was retreating. This structure can frequently be seen from the car windows of the New York Central Railroad. The marginal

FIG. 3.—Ripple marks in the clay at New Windsor.

deposits of gravel and sand have the form of plateaus of two distinct classes:

Class 1.—Gravel terraces and plateaus with undulatory topography on the edge toward the Hudson, which sometimes assumes a more or less kame-like or morainic form, or with the edge next to the Hudson higher than the edge next to the valley wall, and with the dip of the layers of gravel and sand toward the valley wall and downstream. This phase of the drift is the characteristic phase in the Highlands, and is not accompanied by a clay plain.

Class 2.—The second phase of the stratified drift consists of gravel plateaus and terraces with the undulatory edge toward the

valley wall, and the smoother and lower edge toward the Hudson.[1] The inner and higher edge is sometimes marked by distinct kames or by moraine. The structure is delta-like. The layers usually dip at high angles toward the Hudson, and the coarse gravels and sands grade rapidly down the dip of the layers into fine laminated clay. (See Fig. 5, *A* and *B*, and Fig. 6.) In the clay and over the clay there are sometimes masses of till. (Fig. 4.) In the till there are sometimes masses of clay. Over the clay there often is coarse gravel with a subdued undulatory topography, and the contact of the

FIG. 4.—Showing till both above and below the clay at Haverstraw.

gravel and clay is of such a nature as to indicate that the gravel has been forcibly pressed against the clay surface. This phase of the gravel plateaus is the characteristic phase of the Appalachian Valley division of the Hudson Valley, and is usually associated with a wide clay plain. These two classes may be referred to as high-level terraces. On the whole, they increase in altitude from south to north, but not at a uniform rate or continuously. They indicate a water

[1] Some of the smoother plateaus may properly be called subaqueous overwash plains. See R. D. SALISBURY AND HENRY B. KÜMMEL, *Annual Report of State Geologist of New Jersey*, 1893, pp. 266–68; and R. D. SALISBURY, *Glacial Geology of New Jersey*, pp. 130–33.

body in the Hudson and Champlain Valleys as the ice was retreating after making the Brooklyn-Perth Amboy moraine.

Below the level of the high-level gravel plateaus there are two classes of deposits: (1) secondary deltas; (2) river terraces. The former have been recognized with certainty only in the northern Hudson. The latter occur in the northern Hudson Valley and in tributary valleys both in the northern and southern parts of the Hudson. In these lower terraces pebbles of clay occur rarely, evidently derived from the erosion of the higher clay deposits.

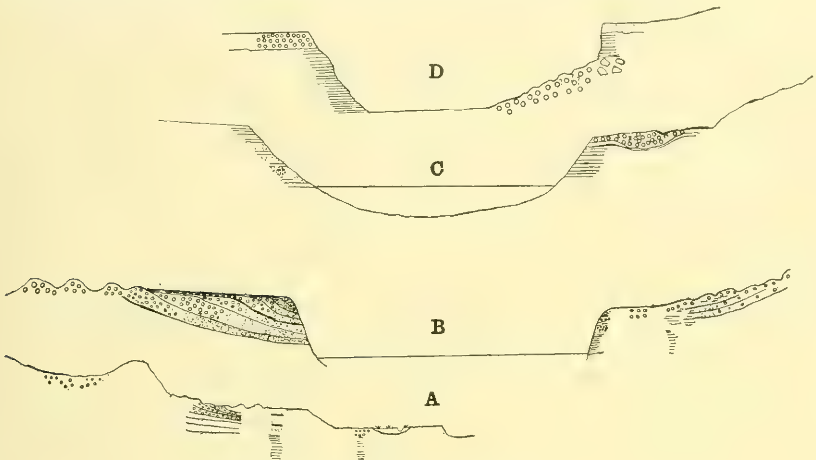


FIG. 5.—Diagrammatic sections:

[*A*, of Haverstraw gravel plateau from west to east; *B*, of Newburg delta and moraine at the left and Dutchess Junction gravel plateau with morainic east edge on the right; *C*, a section similar to and about one mile south of *D; D*, Roseton on the left and the northern part of the Low Point deposits on the right. Parallel horizontal lines represent clay.

In the Hudson Valley this old sea- or lake-floor plain is naturally divided into three portions roughly corresponding with (1) the portion south of the Highlands, (2) the Highlands, and (3) the Hudson Valley north of the Highlands. Deposits in a lowland west of the Palisade Ridge will be described in connection with Division 1.

HUDSON VALLEY SOUTH OF THE HIGHLANDS AND LOWLAND WEST OF PALISADE RIDGE.

From the narrows at Brooklyn northward to the Highlands the land rises gradually, as a slightly rolling upland, best represented by the even crest of the northern part of the Palisade Ridge, and by the

level to which the hilltops reach east of the Hudson.[1] Below the level of this upland to the west of the Palisade Ridge there is a lowland. Below the surface of this lowland 100–150 feet there are

FIG. 6.—Photograph showing gradation of gravel and sand down the dip of the layers into clay, in the part of the Newburg delta north of the Quassaic. The workman's shovel marks the point where one of the layers of gravel and sand at the left changes into clay.

valleys[2] in which there are deposits of gravel, sand, and clay, presently to be described. In the valleys in the southern part of this

[1] *New York City Folio*, U. S. Geological Survey; *Geography* by R. E. DODGE AND BAILEY WILLIS, p. 1.

[2] *Physical Geography of New Jersey*, R. D. SALISBURY, p. 141.

Fig. 7.—Model of New York City and vicinity.
[Copyright by Edwin E. Howell; printed by permission.]

lowland there are salt waters, which in their widest expanse constitute Newark Bay. (See Fig. 1, No. 5, and Fig. 7.)

The upland surface represented by the even crest of the Palisade Ridge is a remnant of the Cretaceous peneplain. The lowland surface represents a later peneplain developed on the softer rocks of the Triassic area.[1] The valleys in this lowland represent erosion in pre-last glacial and post-Pensauken time. The stratified drift in these valleys was deposited largely by ice waters on the retreat of the ice from the Brooklyn-Perth Amboy moraine.

Below the upland surface and at the east base of the Palisade Ridge is the Hudson Valley, now occupied by the waters of the Hudson estuary. Along the sides of the valley and below the waters of the Hudson estuary there are deposits of stratified gravels, sands, and clays similar in origin to those in the lowland west of the Palisade Ridge.

Below the waters of the Hudson estuary and of Newark Bay there are certain submerged channels which are shown in Fig. 8 and will be referred to later.

BROOKLYN-PERTH AMBOY MORAINE.

Across the southern end of both the Hudson Valley and the lowland west of the Palisade Ridge there is the massive and complex ridge which forms the Brooklyn-Perth Amboy terminal moraine.[2] It is popularly referred to as the backbone of Long Island, and it also makes the more conspicuous elevations of the southwestern part of Staten Island. Through this moraine there are two gaps—one at the south of the Hudson and the east end of Staten Island called the Narrows, and the other at the west end of Staten Island occupied by Arthur Kill. (See Fig. 8.)

[1] This is called the Somerville peneplain by Professor W. M. Davis, and the pre-Pensauken peneplain by Professor R. D. Salisbury (*loc. cit.*, pp. 114–15).

[2] See R. D. SALISBURY, *Glacial Geology of New Jersey*, Chap. 9, and *New York City Folio*, U. S. Geological Survey. T. C. CHAMBERLIN, *Third Annual Report*, U. S. Geological Survey, 1881–82, pp. 377–79; WARREN UPHAM, *American Journal of Science*, 1879, pp. 81–92 and 179–209; G. H. COOK AND J. C. SMOCK, Geological Survey of New Jersey, *Annual Reports* for 1877, 1878, and 1880.

FIG. 8.—Map of the drift and of the submerged channels of New York and vicinity.

[Taken from Plate 28 of R. D. Salisbury's *Glacial Geology of New Jersey* and from the *New York City Folio* of the U. S. Geological Survey. Some belts of thicker drift including kame belts and morainic areas are shown which were mentioned in the text of the former, but not included in Plate 28. On Long Island some belts are marked which were mapped partly as kames and partly as till areas. The submerged channels were traced from data obtained from the *U. S. Coast Survey Charts*.]

LEGEND: *A*, belts of thicker drift including kame belts and morainic areas which are believed to mark halting places of the ice. *B*, areas of stratified drift with kames not included in *A*, and including some small areas of dune sand. *C*, mixed till and stratified drift. Till areas are shown in white, submarine channels in black.

1, Raritan Bay; 2, Perth Amboy and Arthur Kill; 3, Woodbridge Creek; 4, Elizabeth River; 5, Newark Bay; 6, Passaic River; 7, Hackensack—city and river; 8, Englewood; 9, Kill van Kull; 10, East River; 14, Sparkill Valley.

DRIFT OF LONG ISLAND AND STATEN ISLAND INSIDE THE BROOKLYN-PERTH AMBOY MORAINE.

Inside or north of the Brooklyn-Perth Amboy moraine a number of positions taken by the ice on its retreat are marked by moraines or kame belts, or other similar phenomena. Near the west end of Long Island at least two, and probably three, such belts are represented more or less discontinuously. (See Fig. 8.) Possibly one such position is represented on Staten Island.

DRIFT OF THE LOWLAND WEST OF THE PALISADE RIDGE AND NORTH OF THE BROOKLYN-PERTH AMBOY MORAINE.

On the higher part of the lowland west of the Palisade Ridge and inside the Brooklyn-Perth Amboy moraine, there is an extensive series of belts of thicker drift, with more or less distinct morainic topography, or elongate belts of kames with the aspect of moraines, which are frequently bordered by plains of gravel and sand with the form of overwash or outwash plains. In some places such aggradation plains have no definite kame or morainic areas at their source. On the lower part of the lowlands there is a complex series of gravel and sand plains or plateaus, some of which head in kames, but others have ice-molded, but kameless, sources.

Some of the plains have delta-like forms and delta-like structures. The elevations of these plains at the south are 20–40 feet, while farther north plains whose structure is unknown have elevations of 80–100 feet.[1] These deposits are found north from the latitude of Hackensack and Englewood well toward the northern border of the state. Underneath the gravel and sand of these plains, or spread out to the southward with little overlying sand or gravel, there is laminated clay which frequently has a thickness of 100 feet and sometimes as great as 215 feet. This clay extends south of the lat tude of Hackensack and Englewood, and is also found to the north.[2]

[1] See R. D. SALISBURY AND C. E. PEET, "Drift Phenomena of the Palisade Ridge," *Annual Report of State Geologist of New Jersey*, 1893, pp. 195–210; and *idem*, "Drift of the Triassic Plain of New Jersey," *Glacial Geology of New Jersey* (Final Report of State Geologist, Vol. V), Chap. 12, and especially pp. 506–13, 595–628, 632–42.

[2] The areal distribution of a large part of these deposits is shown in the maps of the *New York City Folio*, U. S. Geological Survey. See also Fig. 8 of this article.

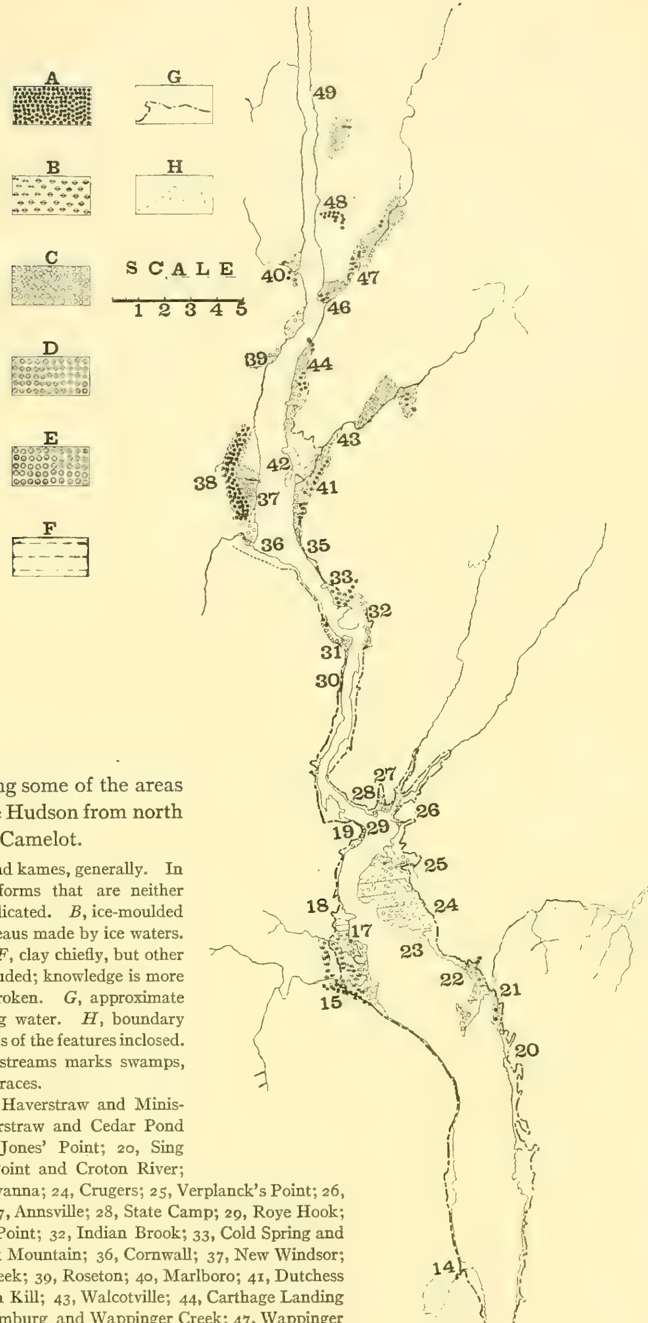


FIG. 9.—Map showing some of the areas of stratified drift along the Hudson from north of Sing Sing to north of Camelot.

LEGEND: *A*, moraines and kames, generally. In some places ice-shaped drift-forms that are neither moraine or kames are thus indicated. *B*, ice-moulded stratified drift. *C*, gravel plateaus made by ice waters. *D* and *E*, secondary deltas. *F*, clay chiefly, but other forms of stratified drift are included; knowledge is more certain where lines are not broken. *G*, approximate limits reached by the standing water. *H*, boundary lines showing approximate limits of the features inclosed. The white space next to the streams marks swamps, flood-plains, and low-level terraces.

14, Sparkill Valley; 15, Haverstraw and Minisceongo Creek; 17, North Haverstraw and Cedar Pond Brook; 18, Stony Point; 19, Jones' Point; 20, Sing Sing (Ossining); 21, Croton Point and Croton River; 22, Croton Landing; 23, Oscawanna; 24, Crugers; 25, Verplanck's Point; 26, Peekskill—village and creek; 27, Annsville; 28, State Camp; 29, Roye Hook; 30, Highland Falls; 31, West Point; 32, Indian Brook; 33, Cold Spring and Foundry Brook; 35, Breakneck Mountain; 36, Cornwall; 37, New Windsor; 38, Newburg and Quassaic Creek; 39, Roseton; 40, Marlboro; 41, Dutchess Junction; 42, Fishkill and Fish Kill; 43, Walcotville; 44, Carthage Landing and Low Point; 46, New Hamburg and Wappinger Creek; 47, Wappinger Falls; 48, Camelot; 49, Poughkeepsie.

DRIFT IN THE HUDSON VALLEY SOUTH OF THE HIGHLANDS AND NORTH OF LONG ISLAND AND STATEN ISLAND.

The deposits of drift of special significance in this area occur north of Ossining (Sing Sing), where the valley begins to broaden out into Haverstraw Bay. Most of the deposits south of here are covered by the "Surficial Geological Maps" of the *New York City Folio*, and are mentioned in its text. The deposits of drift of special significance in this part of the valley belong to the two classes of high-level terraces mentioned above (p. 228). The features of Class 1, similar to those found in the Highlands, are found (1) in a terrace at 120–100 feet A. T. from north of Sing Sing to south of Croton River mouth; (2) at Jones Point; and (3) features of similar import occur at Roye Hook near State Camp, Peekskill. These features are shown in Fig. 9, the first between Nos. 20 and 21, the second at No. 19, and the third at No. 29. To which class some of the features of a high-level terrace from Peekskill toward Oscawanna belong is a question. (See Fig. 9, Nos. 23, 24, 25). The features of Class 2, similar to those prevailing in the Appalachian Valley part of the Hudson, occur at Croton Point and Croton Landing on the east side of the river, and from Haverstraw to north Haverstraw on the west side. (Fig. 9, Nos. 21, 22, and 15 and 17.)

Haverstraw.—The deposits at Haverstraw of interest in connection with this paper are of four types: (1) the narrow moraine at the foot of the Palisade Ridge; (2) a gravel plateau with undulatory topography and delta-like structure at an elevation of less than 120 feet A. T., which is underlain by laminated brick clays, yellow in color above, and blue below; (3) low-level gravel and clay.

1. The moraine: The position of the ice-edge as it rested near the northern base of the Trap Ridge, which farther south makes the Palisades of the Hudson, is marked in the southern part of Haverstraw by a narrow moraine with a west-by-north and east-by-south trend, parallel approximately to the trend of the Trap Ridge. Where well-defined this moraine has a width of one-fourth to one-half of a mile. It has been traced for a distance of about two miles, from a point about one mile southeast of Thiell's Station to within something less than three-fourths of a mile northwest of Short Clove. It extends farther east in the form of a ridge, but with less definition

as Short Clove is approached. At its best the moraine shows a relief between hillocks and hollows of between 20 and 30 feet. (See Fig. 9, No. 15). Some of the hillocks are composed largely of stratified drift, but, so far as exposures show, a considerable part of the moraine is made up of till which is prevailingly of gneissic materials. There are places, however, where it shows a conspicuous red color from the abundance of Triassic constituents.

2. The Haverstraw gravel plateau has been sometimes called the Haverstraw delta. It extends from about the lower edge of the moraine above mentioned northward to Cedar Pond Brook, and descends from an elevation of a little less than 120 feet on the west to 40–60 feet on the east, where it falls off abruptly to a lower plain bordering the Minisceongo and Cedar Pond Brooks.

Fig. 10.—Cross-section of the Appalachian Valley (after Davis).

AB, uplands; *CD*, general valley lowland. Horizontal lining shows clay.

The topography of the plateau for the most part appears at first sight to be quite plain, with a general slope eastward and southeastward. In the northern part, however, it becomes quite undulatory, and there are some depressions as great as 20 feet in depth, one of which is situated in a long conspicuous ridge extending north and south parallel to the road west of it, leading from West Haverstraw to North Haverstraw. This ridge is separated from the higher land to the west by a considerable trough-like hollow. On closer examination much of the surface, which at first sight appeared to be quite plain, is found to be affected by ridge-like undulations and hollows with a relief of 6, 8, and 10 feet These undulations extend eastward nearly to the abrupt east front. (See Fig. 5, *A*.)

Structure and materials: Exposures are abundant in this plateau. In the higher western portion numerous gravel and sand pits show stratified sands and gravels more or less horizontal in the upper few feet, and dipping at high angles below in an easterly and southerly direction. A little eastward these stratified gravels are said to overlie clay, and still farther eastward exposures are of such a nature that it is quite certain that the gravels and sands grade into finer materials, and into clay with alternate layers of fine sand, and finally into the laminated brick clays.

While stratified materials appear to prevail in the capping of the clay, a number of places are to be found where the material is not stratified, and where it has the character of a compact till showing indications, at the contact with the clay, of having been subjected to a pressure which forced the clay and the till together. The contact surface is irregular. (Fig. 4.) The clay surface rises and falls as much as 2 feet in a distance of 10 feet, while the layers of clay show contortion in the upper part. In earlier observations compact lumps of clay were noted in till-like material. Before it was firmly established that till overlies the clay, the writer did not feel sure that in the extraction of the clay for brick-making the lumps of clay had not become artificially mixed with till. It seems reasonably certain now, however, that the observed clay lumps in the till were not introduced artificially. Underlying the clay stratified gravel and sand was observed in some places with a topography which suggested buried kames. In other places till was observed with some constituents that are not present in the overlying till. Flowing springs and flowing wells arising from this underlying gravel and sand indicate that the water has access to these porous layers at higher levels.

North Haverstraw.—The gravel plateau at North Haverstraw very likely was once continuous with that described south of Cedar Pond Brook. It has a general elevation of something less than 120 feet A. T. on its west side, and a large part of its total area is 100 feet A. T. It descends abruptly 100 feet to the meadow along Cedar Pond Brook on the south, and on the northwest it descends abruptly to a plain at about 20 feet A. T. On the northeast the descent is to a kame-like gravel knoll at about 50 feet A. T. On the east there is a similar knoll. Each of these knolls is indicated by a black circle at No. 17 in Fig. 9. On the southeast the descent is to a terrace-like form at 40 feet, and farther south to a ridge of gravel of uncertain origin at 60 feet A. T.

The west and northwest sides of the plateau have a gently undulatory topography, and the surface of the plateau farther east has some ridge-like irregularities that suggest the presence of the ice during its deposition.

Materials and structure: There are no good exposures in this conspicuous plateau, although exposures occur in the lower gravel

forms to which the steep edges of the plateau descend. The indications from the surface and from well data are that it is composed of gravel and sand. A well on the top of the plateau near the west side at the house of Mr. Neely is reported to have penetrated 120 feet of gravel and sand from an elevation of 100 feet A. T. without reaching rock.

The kame-like gravel knoll at the northeast edge of the plateau is situated south of the North Haverstraw Station of the West Shore Railroad. An exposure shows about 20 feet of coarse gravel. Farther south, east of the railroad, where the gravel likewise has a kame-like form, the layers dip north and south and east. North of these kames toward Stony Point clay occurs up to 40–60 feet, and has a form which may be due to erosion.

Low-level gravel, and clay. What appear to be low-level terraces derived from the erosion of the higher gravels have been observed in the form of discontinuous shoulders on the north side of the Haverstraw gravel plateau on the slope to Cedar Pond Brook at elevations of 60 and 40 feet. A 40-foot level on the southeast side of the North Haverstraw plateau, and also a 60-foot level southwest from the 40-foot level, may represent a product later in origin than the plateau itself. It may be said, however, that where the level of stratified drift varies so greatly as it does in this region it is not easy to determine positively that the shoulders of limited area and uncertain relations are of later origin than the higher gravels, and do not represent remnants of undulations descending to the lower levels made while the ice was present. A wide plain extending along the water front from near Short Clove to Grassy Point, with an elevation by the topographic map of less than 20 feet A. T., has been so worked over in the making of bricks that it is difficult to say what was its original height and extent. Some exposures have been observed in it in which the materials included rounded pebbles of clay, evidently derived from the erosion of the higher level clays. In exposures near at hand and at about the same level the layers have a southerly dip at a high angle, thus suggesting lower-level delta deposits made from the erosion of the higher gravels and clay. At Grassy Point (south of No. 17, Fig. 9) there are deposits in this lowland which were made in the presence of the ice.

No exposures which reveal the structure occur in the 60-foot and

40-foot levels south of Cedar Pond Brook. The 40-foot level at North Haverstraw is well exposed. In no part of the exposure was the delta structure seen which is so common in the high-level gravels,

FIG. 11.—The Catskills and the lowland in the Appalachian part of the Hudson Valley.

[From A. P. Brigham, *Geographic Influences on American History;* courtesy of Ginn & Co.]

and there is said to be no clay underlying the stratified gravel here for a considerable depth at least.

Interpretation: (1) Ice present with its edge resting on the moraine at the foot of the Trap Ridge and with a general west-by-north and east-by-south direction on the west side of the Hudson.

(2) The ice retreated so that, either at one time or at successive positions, its edge occupied the Haverstraw and North Haverstraw gravel plateaus.

(3) The ice waters discharged into a standing body of water and built up the deposits of gravel and sand, with the steep dipping layers of gravel rapidly grading into sand and then into clay. The clay was deposited on the irregular surface of the drift previously deposited.

FIG. 12.—Part of the Newburg delta, on the south side of the Quassaic. Looking west.

(4) The ice, either by re-advances, or because of more favorable conditions in some places than in others while continually present, worked over the clays, producing some of the contortions observed, and involving masses of clay in the till which it deposited over the clay in favorable places. The water-worn gravel was in places brought under pressure, and the contact of the clay with the gravel was thereby made more intimate.

(5) On the retreat of the ice and the fall of the water-level the higher-level gravels were eroded by the Minisceongo and Cedar Pond Brook, thus producing deposits at lower levels. Whether there are remnants of lower-level deltas cannot be confidently stated. They would naturally be expected.

(6) After deeper erosion by the streams than the present Hudson level, submergence took place, thus drowning the mouths of the tributary streams.

Croton.—On the east side of the river at Croton Point, and Croton Landing, deposits of similar import occur, but not identical in detail, with those on the west side of the river. Lack of space forbids detailed description.

Oscawanna—Crugers—Peekskill.—Clays and gravels: The clays and gravels in the city of Peekskill and south to Oscawanna show phenomena which in some features are similar to, and in other features are unlike, those at Haverstraw and Croton. They are evidently deposits made later than the last-mentioned deposits. Their relations, however, to any marked and definite position of the ice-edge are not so well shown. The approximate area of these deposits is shown in Fig. 9 between Nos. 23 and 25.

The deposits in this region are notable for their irregularity in level. The clay surface varies from an elevation approaching 100 feet A. T. to tide-level. It is in most cases covered with sand, or gravel, and in a broad statement it may be said that the finer materials predominate at the south, while at the north the materials overlying the clay include both fine materials and coarse gravels with bowlders up to five feet in diameter. In one or two instances till has been found overlying the clay in this region.

The structure of the stratified materials overlying the clay even at high levels does not generally show the high angle of dip so common in the high-level gravels at Haverstraw and Croton.

The high-level terrace has an elevation of 100–120 feet A. T. Parts of it, however, reach lower levels—60–80 feet A. T., and perhaps less. It is somewhat difficult to discriminate between what may properly be called high-level terrace and what may properly be called low-level terrace. Terraces at low levels exist at 60, 40, 30, and 10–20 feet A. T. In general, these terraces are covered by gravel and sand. The gravel is sometimes very coarse, containing bowlders as large as five feet in diameter. The relations to the clay are not always distinguishable. It is not an uncommon relation, however, to find these low-level gravels much lower in level than clay in the immediate vicinity. It is questionable, however, if in all cases this relation has been brought about by the erosion of the higher-level deposits. It is conceivable that some of the low-level deposits are original deposits by the ice water, which simply failed to build up at

FIG. 13.—Showing principal areas of stratified drift along the Hudson from latitude of South Schodack to north of Saratoga Springs.

LEGEND: *A*, moraines and kames, generally. In some places ice-shaped drift-forms that are neither moraine or kames are thus indicated. *B*, ice-molded stratified drift. *C*, gravel plateaus made by ice waters. *D* and *E*, secondary deltas. On the Batten Kill some of the ice-water deposits may be included in the areas covered by this device. *F*, clay chiefly but other forms of stratified drift are included. Knowledge is more certain where lines are not broken. *G*, approximate limits reached by the standing water. *H* boundary lines showing approximate limits of the inclosed features. The white space next to the streams marks swamps, flood-plains, and low-level terraces.

62, South Bethlehem, Sprayt Kill and Onisktethau Creek; 63, New Scotland; 64, Voorheesville; 65, Newtonville; 66, Schenectady; 73, South Schodack; 74, East Greenbush; 75, Teller Hill; 76, Troy; 77 Mechanicsville; 78, Ballston Lake; 79, Round Lake; 80, Maltaville; 81, Saratoga Lake; 82, Ballston Spa; 83, Lonely Lake; 84, Saratoga Springs; 85, Moreau Pond; 90, Hoosic River; 91, Batten Kill; 92 Fort, Miller; 93, Moses Kill.

these particular places to the level reached in adjacent places. It may be said that this relation is more clearly shown by phenomena seen elsewhere. The facts in this locality are sufficiently doubtful, at any rate, to justify caution in asserting the erosion origin of the irregularities in the clay. However, there are some facts which seem to indicate a considerable amount of erosion of the clay in this region and subsequent deposition of gravel in the clay channels.

Jones Point and State Camp near Peekskill.—At Jones Point a narrow terrace less than a mile in length occurs on the right side of the Hudson. It is made up mainly of stratified gravel and sand and a little clay, and formerly contained more clay.[1] The terrace has an elevation at its north end of about 100 feet A. T., and at its south end of about 60–80 feet, and at present, in places at any rate, is higher toward the Hudson than toward the valley wall. See Fig. 9, No. 19.

At State Camp (28) near the mouth of the Peeks Kill there is a gravel plateau with an elevation of 100 feet A. T. whose flat top is used by the New York state militia as a camping and parade ground. This plateau continues up the valley of Sprout Brook with some breaks, to a point about one mile northeast of Annsville (27), where it has an elevation of 140–160 feet A. T. It was not studied beyond this point. It also extends northward up the valley of the small tributary north of State Camp and southeast of Wallace Pond. Its greater development occurs, however, at State Camp on the right bank of Peeks Kill. A small remnant occurs farther upstream on the left bank. While the plain surface as a whole rises upstream, the northern portion of it at State Camp slopes eastward—a fact of some significance perhaps in determining the history of the plateau.

The exposures in this plateau show gravel overlying clay. The clay reaches higher above sea-level near the extremity of the plateau than farther upstream, thus indicating a gradation of coarse materials from upstream into the fine clay. Low-level terraces occur farther downstream on both right and left sides of the stream at 30–40 feet A. T.

Roye Hook.—West of the plateau near the State Camp Station of the New York Central Railway there is an isolated hill of small dimensions, reaching an elevation of 100 feet A. T. This is called

[1] See H. Ries, *Tenth Annual Report State Geologist of New York*, p. 114.

Roye Hook (29, Fig. 9). At its base, both on the north and on the south, there are low-level terraces at about 30 feet. In the Roye Hook hill a large gravel and sand pit shows about 10 feet of fine sand and gravel overlying 5 feet of silt, both sand and silt being horizontally stratified, or nearly so. But under the silt there is about 85 feet of coarse gravel and sand, with layers dipping at a high angle eastward and southeastward. The gravel and sand in this lower portion of the exposure were not observed to grade into clay, as they were observed to do at Croton, and as they apparently do at Haverstraw. The phenomena at Jones Point and Roye Hook are more nearly allied to deposits which occur in the Highlands than they are to those that occur in the broader part of the valley to the south. These characteristics are discussed in the description of the Highlands phenomena.

THE HIGHLANDS OF THE HUDSON.

As indicated above in the description of the general features of the Hudson, south of Newburg and Fishkill the Hudson leaves the Appalachian district and crosses through the plateau to the south in that part of its course designated the Highlands of the Hudson. The features of the rock valley here differ radically from those at the north, and in place of a broad dissected lowland between distant uplands, like that in the Appalachian Valley, or of the broad amphitheater between distant uplands like that at the north edge of the Palisade Ridge at Haverstraw, we have the upland descending abruptly from elevations of 1,100 and 1,400 feet to the waters of the estuary, which is here generally from four-fifths to seven-tenths miles wide, and reaches a maximum width of one and three-fifths miles.

In this narrow valley the gravel plateaus are present, but if there is a clay plain, it is covered by the waters of the estuary, or is represented by a few limited remnants only.

The gravel plateaus in the Highlands of the Hudson have characteristics which are typical of Class 1 above described, and indicate the presence of the ice in the valley while these deposits were accumulating. There are situations however, where streams of water came from the ice outside of the immediate Hudson River valley and deposited their loads on slopes toward the center of the valley. Such

phenomena occur where streams head northward from their debouchure, and are represented, it is believed, by a part of the State Camp deposits on the southern edge of the Highlands. The gravel plateaus of the Highlands that were examined are (1) at West Point and south toward Highland Falls (30); (2) at Cold Spring (33) and south toward Garrison. The stratified drift at Roye Hook near State Camp, perhaps part of the State Camp plateau where the surface slopes east-

FIG. 14.—Looking across the clay plain of the upper Hudson.
[Photograph by W. S. McGee.]

ward, and the Jones Point plateau, on the southern edge of the Highlands have characteristics similar to those in the Highlands and indicate a similar disposition of the ice in respect to the valley when they were building.

North of West Point in the Highlands there is little left of any former valley filling, if the valley ever was filled. One or two miles south of Storm King, on the right bank of the Hudson, a remnant of clay in a terrace form was observed at an elevation estimated at 60 feet, and nearer Storm King another remnant was observed. On the left bank there are several remnants of clay or gravel, the most conspicuous of

which is a terrace of coarse gravel on the south side of Breakneck Mountain (35, Fig. 9) with an estimated elevation of 80 feet.

The weight of evidence in this part of the Hudson indicates that the ice protruded as a tongue down the valley, and that it was influential in shaping the edge of the plateaus toward the Hudson. An alternative hypothesis is that the ice retired in a northeasterly direc-

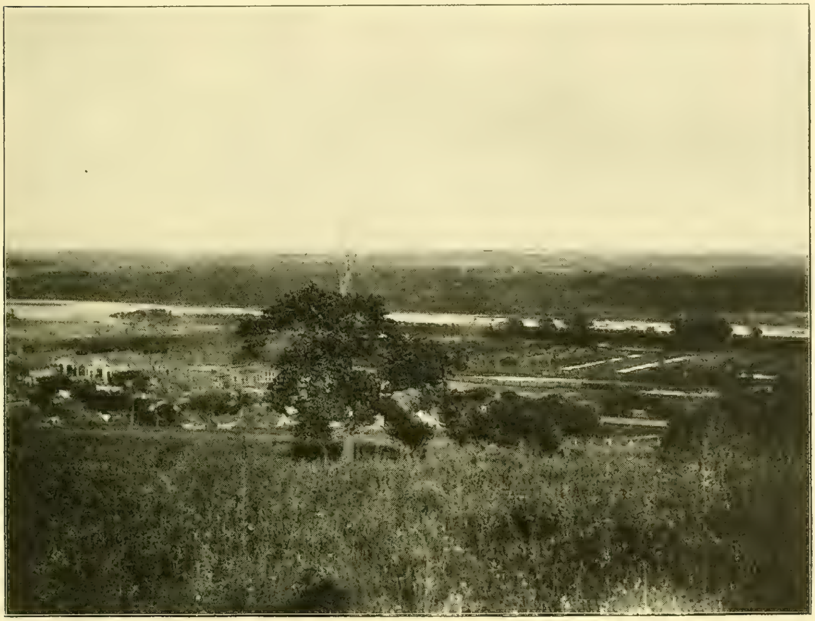


FIG. 15.—Looking eastward from the bluffs north of Albany across the trench of the Hudson, cut into the clay plain.

tion; that the plateaus on the west side of the valley were made first and had their east edge shaped by the ice-front; and that later those on the east side of the valley were constructed and had their east edge shaped by the ice. This alternative hypothesis, however, does not explain the eastward-dipping layers of the plateaus on the east side of the valley, nor does it explain the apparent lower elevation of some parts of the terraces on the east side next to the valley wall. It would explain successive undulations from lower levels near the Hudson to higher levels away from the Hudson, such as are found at Cold Spring (33, Fig. 9).

HUDSON VALLEY NORTH OF THE HIGHLANDS.

The valley north of the Highlands has been considered the northeastward continuation of the Greater Appalachian Valley. It lies between the upland surface on the east, which in New England is called the New England Plateau, and on the west it is limited by the Alleghany Front which is the steep slope from the Alleghany Plateau to the Greater Appalachian Valley, and of which the dissected edge is called the Catskill Mountains. Below the level of these eastern and western plateau surfaces there is a broad lowland. Below the level of this lowland surface there are deep valleys. In the bottom of these valleys there are the deposits of stratified drift which have the form of an old lake- or sea-floor. Below this old lake- or old sea-floor there are valleys and other depressions. In the bottom of the Hudson Valley is the Hudson estuary, and beneath its waters is the submerged Hudson channel described below. In this region and farther to the southwest, upland and lowland surfaces in the Appalachian district have been interpreted as representing peneplains at two or more levels.[1] The interpretation of the preglacial history of the valley is beyond the scope of this article. The writer wishes to get before the reader a general picture of the region only, without reference to the preglacial history. (See Figs. 10 and 11).

In the Appalachian part of the Hudson the drift phenomena may be described in seven sections: (1) the Fishkill-Dutchess Junction Fig. 9, Nos. 42, 41), and Newburg-New Windsor deposits (38, 37); (2) high-level terrace north of Fishkill south of 44 and north of 42; (3) deposits from Carthage Landing to Lowpoint on the east side of the Hudson and at Roseton on the west side (Nos. 44 and 39); (4) New Hamburg gravel plateau and stratified drift on Wappinger Creek (Nos. 46 and 47); (5) Camelot kames (No. 48); (6) deposits north of Camelot from Poughkeepsie to Catskill; (7) deposits from north of Catskill to north of Glens Falls (Fig. 13).

The deposits in Division 1 are similar in import to those in Division 7, and are very much like the phenomena at Haverstraw and Croton.

[1] See R. D. Salisbury, *Physical Geography of New Jersey*, pp. 8–14, 83–85, 94–98; Bailey Willis, "Northern Appalachians," *National Geographical Society Monographs*, Vol. I; C. W. Hayes, "Southern Appalachian," *ibid.*, and W. M. Davis, *Proceedings of the Boston Society of Natural History*, Vol. XXV (1891), pp. 318 *et seq.*

The phenomena in Division 2 are somewhat like those from south of Peekskill toward Oscawanna, and indicate the presence of the ice in the valley near the north edge of the terrace when the deposits found here were being made. The Carthage Landing-Lowpoint and Roseton deposits indicate the presence of the ice in the valley when adjacent stratified drift at higher levels was accumulating. The New Hamburg gravel plateau and Wappinger Creek stratified drift indicate the presence of the ice in the valley at the edge of the New Hamburg plateau while the ice in the higher lands was retreating through the Wappinger Creek Valley.

I. NEWBURG-NEW WINDSOR AND FISHKILL-DUTCHESS JUNCTION.

These places are situated on opposite sides of the river. On each side the Haverstraw phenomena are repeated. Gravel plateaus underlain by clay are situated next to the river, and morainic phenomena occur on the higher land away from the river. The gravel plateau at Newburg is more delta-like in form than either at Haverstraw or Fishkill-Dutchess Junction. (See Fig. 12.) In the latter places the surface is marked by undulations similar in kind to, but more subdued than, those in the moraines on the adjacent higher land. Masses of till are found at Dutchess Junction in the clay, and ripple marks are found in the clay at New Windsor. (See Fig. 3.)

Interpretation: The interpretation of these deposits is similar to that of the Haverstraw deposits. It is difficult to see how the ice of a single ice-lobe can retire from a valley both to the eastward and to the westward, either simultaneously or successively, unless it be by the making of an embayment in its front. The evidence here, like that at Croton Point and Haverstraw, points to an embayment of the ice-front with at least wings of ice extending farther down the Hudson on each side. If the interpretation of the Jones Point, Roye Hook, and West Point-Cold Spring phenomena be correct, it would seem that the front changed from a protruding tongue in the Highlands and immediately south, to an embayment at Newburg—New Windsor and Dutchess Junction—Fishkill. This is similar to the interpretation of a protruding ice tongue south of Croton Point and Haverstraw and an embayment at those places.

The level to which the waters of the Hudson water body reached

seems to be 140 feet. It may have reached somewhat higher. The only means of determining this limit seems to be the maximum limit of the delta structure. The presence of kames or moraine does not fix an upper limit to the water, as indicated by the North Haverstraw kame-like bodies, at low levels and by kames at Camelot and other places to be mentioned hereafter.

Low-level terraces on the Fishkill and Quassaic have the same import as those at Croton. It is a question how much erosion has taken place in the Hudson Valley itself. If the ice was on the valley sides and the waters discharging into the valley which was free from ice, it would be expected that the valley would be filled entirely across up to the level required by the slope of the deposits from each side. Since the clay would naturally take a very gentle slope if the valley was free, it would be expected to fill to a height somewhat less than the height of the clay on each side, but not very much less. Altogether it seems probable that the erosion here has been more than 100 feet, while in regions immediately north it is very much less than this.

II. HIGH-LEVEL TERRACE NORTH OF FISHKILL.

One and one-quarter miles north of Fishkill a sand-and-gravel-capped clay terrace at 100 feet at its outer edge and 120 feet at its inner edge extends northward for about one mile, with a width of less than one-quarter of a mile up to three-quarters of a mile. The overlying gravel and sand have a depth of 6–10 feet, and the layers dip south. Near its north end gravel and sand occur at a higher level, with a slightly undulatory topography, which may mark the ice-edge on the land when the terrace was building in the Hudson water body. (See Fig. 9 south of No. 44 and north of 42.)

III. CARTHAGE LANDING-LOWPOINT AND ROSETON.

At the northwest margin of the above-mentioned 100–120-foot terrace a lower terrace of gravel-capped clay occurs at 20–40 feet A. T. The clay in this terrace varies in elevation from sea-level or below to 40 feet above sea-level. The gravel above the clay is coarse and contains some sink-like depressions. (Fig. 5, *C*.) It extends from a point one and one-quarter miles south of Carthage Land-

ing to a point three-quarters of a mile north of that place. For a half mile at its southern end it borders the undulatory gravel area mentioned above in connection with the 100–120-foot terrace. Nearer its north end it is separated from a higher deposit of sand-capped clay by a till area which has a slightly undulatory topography. (Fig. 5, *D*.) Opposite this low terrace, at Roseton and north toward Danskammer Light, a gravel-capped clay deposit occurs at a slightly higher level, with a terrace form. There are two hypotheses to explain these relations: (1) The deposits at Roseton once extended entirely across the valley and have since been eroded, and the 20–40-foot terrace is the product of erosion of the higher deposits. (2) The second hypothesis is that the Roseton gravel-capped clay terrace and the high-level clay deposit on the east side of the Hudson were never continuous, but that the ice occupied the valley when they were made, and stood on the 20–40-foot gravel terrace, but failed to build it as high as the 100–120-foot terrace to the south, or the Roseton terrace to the west and the clay to the east. The sinks in the 20–40-foot terrace, and the faint undulations in the till on he slope between the 20–40-foot terrace and the higher clay, bear this out. If this is the correct interpretation, it is a case similar in kind to the kame-like knolls near the North Haverstraw gravel plateau, and also like the phenomena just south of Peekskill near Verplancks. Under this interpretation the 20–40-foot terrace may or may not once have extended entirely across the valley. Under the first hypothesis both the high-level and the low-level terraces formerly extended entirely across the valley. It may be objected to the second hypothesis that when the ice had retired to New Hamburg, and the clays and sands and gravels were accumulating, some of the finer materials at least should have been carried south into this unoccupied part of the valley. This argument would be especially strong if the Hudson water body was subject to tides whose ebb would tend to carry the fine detritus down into this space. It is, however, not at all necessary to believe that the valley between these two terraces was unoccupied at this time. If the valley was occupied, it was by a mass of stagnant ice. There is evidence elsewhere that such masses of stagnant ice were left in the valley.

IV. NEW HAMBURG GRAVEL PLATEAU AND WAPPINGER CREEK STRATIFIED DRIFT.

A gravel plateau occurs at New Hamburg (46), which has a width in a north-south direction of about one-half mile, and connects with stratified drift which extends upstream to the northeast four miles or more, and spreads out to broader dimensions. It has an elevation at its west edge of 100 feet A. T., and a plain surface which rises upstream; and at Wappinger Falls (47), at an elevation of 140 feet A. T., it has a topography which indicates the presence of ice. Farther northeast kames occur in small areas. The edge of this plateau is steep at the northwest side, but farther south, and east of New Hamburg village, it falls off in undulations, which indicate the presence of the ice during its formation. Exposures in this plateau in this lower portion show layers of gravel and sand with dips west in the western part, and east in the lower portion of the eastern part. Apparently this gravel and sand grades into clay farther east. It will be noted that this would be upstream as the Wappinger Creek now flows. The easterly dipping layers are interpreted as the fore-set beds (of Davis) and the clay as the bottom-set beds. The westerly dipping layers are interpreted as the back-set beds. Farther upstream, just east of the Print mills, near the point where the surface topography indicates the co-operation of the ice in forming the plateau, gravel and sand in considerable thickness overlie silt and yellow clay which reach 60 feet A. T. or more. Blue clay was observed farther south on the left bank of the creek. The layers of gravel and sand dip west and southwest.

Low-level terraces: In the village of Wappinger Falls a lower terrace at 40–60 feet is to be seen, and also one at 20 feet. Both are made of gravel 2–3 inches in diameter. Farther downstream a terrace occurs at 30 feet A. T.

V. CAMELOT KAMES.

Near Camelot kames unassociated with the gravel plateau occur in a valley tributary to the Hudson within 20–40 feet of sea-level, and in the immediate Hudson Valley within 60 feet of sea-level. (Fig. 9, No. 48.)

VI. NORTH OF CAMELOT TO NORTH OF CATSKILL.[1]

From north of Camelot to Catskill the study of the deposits was made largely in passage, so that the relations of the deposits to the successive positions of the ice-edge cannot be stated. These fugitive observations indicate a general higher altitude of the deposits next to the valley side and a lower altitude next to the Hudson. They also indicate an alternate increase and decrease in the elevation both in he present Hudson bluffs and farther back from the river, and this is interpreted as indicating more than one stand of ice in this area. South of Poughkeepsie there is a pitted plain at 140 feet A. T. with a steep descent toward the Hudson, the origin of which is unknown. Gravel was observed at various points along the West Shore Railroad from West Park to Ulster Park, at elevations of 100 and 140 feet A. T. Clay was observed nearer South Rondout at 140 feet, and in South Rondout clay underlies sand which has an elevation of 150 feet. At Kingston along the Hudson a sand-capped clay terrace occurs 220 feet A. T., while farther west along the West Shore Railroad a plain at 180–200 feet A. T. is coated with sand and gravel that are said to be underlain by clay.

North of Kingston the clay has an elevation of 100–140 feet in the Hudson bluffs, and a higher elevation west of the bluffs, where sand covers the surface. At Glasco the clay has an elevation of 140 feet in the river bluffs and 180 feet along the West Shore Railroad two and one-half miles to the westward. At Saugerties and north toward West Camp it has an elevation of 140–160 feet. At Catskill it has an elevation of 100–120 feet, and a plain surface which has been trenched by the Catskill and its tributaries. It has been described here by Professor W. M. Davis, who has also described the delta of the Catskill.[2]

VII. NORTH OF CATSKILL TO NORTH OF GLENS FALLS.

Old lake-floor or old sea-floor.—In the Appalachian Valley part of the Hudson north of Catskill, and perhaps from north of Poughkeepsie the first approximation to a correct picture of the topography

[1] For places mentioned in this division see Fig. 1.

[2] *Proceedings of the Boston Society of Natural History*, Vol. XXV (1891), pp. 318–35.

is that of a plain descending gradually from the valley sides to the bluffs (of clay generally) bordering the present Hudson. The elevation, on the whole, increases from the south, where it is 100 or 120 feet to 180 feet, toward the north, where it is 220–240 feet along the bluffs of the present Hudson. From these elevations marking the bottom of the trough or the meeting of the slopes of the sea- or lake-floor, the plain rises eastward and westward to the higher land marking its limits. (See Fig. 14.)

Gravel plateaus and deltas.—Above the plain on the east and on the west rise gravel plateaus, some of them delta-like in form, which represent approximately the level of the waters when the floor above described was being built up. These gravel plateaus and deltas are found at the following places: On the left bank—(1) South Schodack and northwest at 340–360 feet; (2) Troy, 300 and 360 feet (?); (3) Hoosick River, 360 and 280–300*[1] (?) feet; (4) Batten Kill, 380–400 (?) and 300 feet; (5) At Glens Falls and vicinity, 460 (?), 389, 340*, and 280–300* feet. On the right bank—(1) South Bethlehem, at 300, 240*, and 200–220* feet; (2) at Maltaville, 340–360 feet; (3) at Saratoga and vicinity, 400 (?), 320–340, 300, and 260 feet; (4) southwest of Glens Falls, 340* and 380 feet—a continuation of the Glens Falls levels of the left bank.

The plateaus descend abruptly toward the plain. The layers of coarse gravel and sand of which they are generally made may sometimes be seen to dip at high angles in the same direction and to grade down the dip into the fine materials, and into the clay which makes up a large part of the plain. They are like those of Class 2 of the lower Hudson. The height of the gravel plateaus above the level of the floor varies from 160 to 180 feet on the north to 100–120 or 140 feet in the southern part of this area. While these gravel plateaus descend abruptly toward the old lake- or old sea-floor, and the stratification bears the significant relation to the clay plain mentioned above, the relation of the gravel plateaus up the slope of their surface is just as significant. When traced back they are found to connect,

[1] The stars indicate secondary deltas. Perhaps the 300-foot Troy delta should be considered secondary. Perhaps a part of the 300-foot delta on the Batten Kill is not secondary. It has been seen only in its northern part. Its southern part as represented on Fig. 13, No. 91 is hypothetical.

(1) with valley trains leading down from positions marking the ice-edge during its retreat: or (2) they head directly in kames or other morainic developments which are just as significant in showing the relation of the gravel plateaus to the source from which the material was derived, and from which emanated the waters that transported the delta materials to their present resting place. These kames and moraines have been traced back from the immediate Hudson Valley in a few cases, and have been seen to develop into fairly well-defined morainic topography, while in the lower lands the morainic phenomena are more subdued. Such kames and moraines are found at the following places: (1) At the eastern and northeastern margin of the South Schodack gravel plateau. The East Greenbush kame area makes a part of this belt. (See Fig. 13, Nos. 73, 74.) (2) The Teller hill kames (No. 75), which are fronted by clay without an intervening gravel plateau. (3) The line of kames and moraine extending from North Albany to Newtonville (No. 65.) (4) Kames at Troy (No. 76). (5) Glen Lake-Hopkins Pond kame belt north of Glens Falls (Fig. 18, Nos. 87 and 89. (6) Kames between New Scotland and Voorheesville (Fig. 13, Nos. 63 and 64.) (7) Kames at Saratoga Springs (Fig. 13, No. 84.) (8) The Moreau Pond belt of kames (No. 85.) That the relation of this kame belt to the gravel pla eau east of it is similar to the relation of the kames and gravel plateaus mentioned above, is not certain.

The surface of the gravel plateaus is sometimes marked by ridges or by deep sinks. The clay plain at the outer edge of some of these plateaus has a higher level than at the same edge of the plain farther north, or the reverse may be true. The clay plain sometimes fronts kame areas without an intervening gravel plateau, and the top of the kame area may be lower than the level of the gravel plateau immediately adjacent. On some of the streams, notably the Hoosick River, deltas occur without the undulatory surface. From north of the latitude of Mechanicsville to the northern part of Saratoga Springs, the western part of the lowland is occupied by a succession of gravel plateaus (area 50–75 square miles), with discordant levels which are separated by depressions having a general northeast-southwest direction, and in the bottom of which are lakes such as Round Lake, Saratoga Lake (with a length of 5–8 miles and a width of 2 miles),

and Lonely Lake. Probably Ballston Lake is thus situated. (See Fig. 13.)

Under several of these gravel plateaus, over wide areas, clay is reported. In the bottom of the Round Lake depression there is till, and a limited coarse gravel area with deep sinks in it, although clay and stratified drift rise in steep faces to the north and to the west, and perhaps in other directions. It is believed that these northeast-southwest depressions were occupied by masses of stagnant ice while subsequent plateaus to the northwest were being built, and that the northeast-southwest trend of the depressions indicate something of the direction of the ice-edge as it retreated. At Glens Falls [1] and north a succession of gravel plateaus is believed to mark the successive positions of the ice-edge in a similar way, but they are not separated by wide depressions, or depressions of any kind so generally. Below the level of these gravel plateaus are secondary deltas derived from higher gravels by erosion. It is believed that they have been recognized at South Bethlehem (two levels—one on Sprayt Kill and one on the Oniskethau) (Fig. 13, No. 62), on the Hoosick River (Fig. 13, No. 90), on the Batten Kill near Schuylerville (Fig, 13, No. 91), and on the Hudson in the vicinity of Glens Falls (two levels) (Fig. 18, Nos. 94 and 86.)

Elevations above old lake- or old sea-floor.—Above the plain in situations not confined to its borders there rises another class of elevations, some of which were islands in the sea or lake, when the gravel plateaus and deltas were being made. These hills sometimes are drift hills. More often they are drift-covered rock hills. Such islands may be seen in the following places: [2] (1) hill northeast of Saratoga; (2) highland east of Saratoga Lake; (3) hills north and south of Mohawk River; (4) hills southeast of Albany; (5) hills south of New Baltimore and at numerous places southward, where the elevations are ridges elongate in a north-south direction. Some of these hills may have formed shallows only, at the highest stage of the Hudson water body, but most of them were distinct islands and served to break the water body up into several more or less separate portions. There were doubtless other shallows or islands, and the elevations

[1] See also WARREN UPHAM, *American Geologist*, Vol. XXXII (1903), pp. 223–30.

[2] For these elevations see Fig. 13.

that made shallows at the highest stages of the water body must have produced islands and peninsulas at lower stages.

Depressions below old lake- or old sea-floor.—Below the level of the sea-floor or lake-floor plain there are two classes of depressions: (1) lake basins and similar depressions not occupied by lakes; (2) valleys produced by erosion. The depressions occupied by lakes are those like the Saratoga Lake basin and Round Lake basin, the origin of which has been referred to above and will be discussed below. The basins may be small—a few yards across and shallow; or they may be like the basin of Saratoga Lake, 5–8 miles in length and $\frac{1}{4}$–2 miles in width, and with a depth below the plain surface of 60–100 feet, plus the depth of the water in the lake.

The second class of depressions below the old lake- or old sea-floor are the valleys of the present streams, of which the Hudson is the chief. (Fig. 15.) Below Troy the Hudson is now an estuary, but above that place the tide does not reach. The course of the Hudson is interpreted as marking the trough of the depression down to which the old sea- or lake-floor sloped from each side, and which was followed by the main stream when the floor emerged from the waters in which it had been built. Some of the details in the course of the Hudson may be explained as due to the greater building out along one side of the lake or sea, as for example the westward bend of the Hudson opposite the mouth of the Hoosick River, where the building out of the delta from the eastern side of the valley crowded the depression farther out into the midst of the plain than to the north or to the south beyond the influence of the delta deposits. This westward bend amounts to about two miles. There is no doubt that similar explanations will account for the fact that the Hudson is nearer one side of the valley than the other in different portions of its course, and for other details; but it is probable that other slopes of the floor were the resultant of the interaction of several factors—the original topography of the valley, the rate of deposition by the agencies building up the floor, and the length of time the building continued. At any rate, the course of the Hudson may be considered a consequent course determined by the slopes of the old lake- or old sea-floor across which it flowed when the floor emerged from the lake or sea that had occupied it. Since that time it has trenched its course below the level of

the plain 150–170 feet north of Athens, 190–200 feet at Albany, and 80 feet near Fort Edward. This channel is now covered by tide-water to a depth varying from 10–25 feet at Albany to 15–50 feet north of Athens. This depth of water is included in the above estimates of erosion, from Albany south.

The tributaries of the Hudson have courses that are as significant as that of the main stream itself. The larger streams and the longer small streams that head in the country beyond the limits of the plain and above the level of the Hudson water body descend in general by rather steep slopes to the plain, cross the plain on gentle gradients and descend abruptly near their mouths to the Hudson (Fig. 16, *A*). On

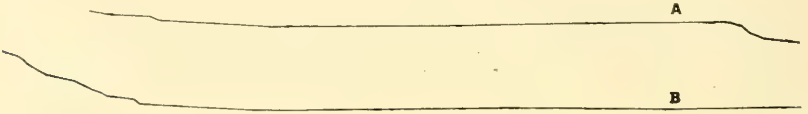


FIG. 16.

A, profile characteristic of streams tributary to the upper Hudson, or flowing either into the Poultney-Mettawee or Fort Edward Valley; *B*, profile characteristic of streams crossing the clay plain and flowing into northern Lake Champlain.

the smaller streams in general this steep slope is not far from the Hudson, and on the larger streams in general it is less abrupt and is farther back from the Hudson. The courses of these streams like that of the Hudson have been determined with few exceptions by the topography of the old lake- or old sea-floor, and one may picture the streams as extending their courses across this floor following the slope of the land as the Hudson water body receded. To these consequent streams subsequent tributaries have no doubt been added, and to the original consequent character of the stream gradients has been added the steep gradient found at the mouth of so many of the streams. The full explanation of this will be taken up later, but it may be said here that this steep gradient is due to so rapid a cutting down of the valley of the Hudson that the smaller and weaker tributaries were unable to keep pace with it. The reason for this will appear later. In some cases the failure of the tributaries to keep pace with the Hudson in its downcutting is due partly to the disadvantage of a hard rock-bed, with which the Hudson did not have to contend.

SUBMERGED CHANNEL OF THE HUDSON.

The submerged channel extends from Troy, the limit reached by the tides, through the Narrows of Brooklyn and beyond out to the outer edge of the overwash plain fronting the Brooklyn moraine. Beyond this there are a number of channels, but none can be considered a continuation of the channel through the Narrows until opposite Sandy Hook, where a channel begins that can be traced southeastward to the forty-one-fathom line. (See Fig. 17.) Whether this should be considered a continuation of the Narrows channel will be discussed later.

Extra-morainic channel.—This channel can be traced from a point opposite Sandy Hook southeastward and ends at the forty-one-fathom line,[1] eighty nautical miles from Sandy Hook. In depth below the plain into which it is cut it varies from zero to 90 feet. Ten miles from Sandy Hook it has a depth of 48 feet, and increases south-eastward to 90 feet, and again decreases to zero feet, at the forty-one-fathom line. Beyond this channel, after an interval, there is a much deeper ravine, with which this paper is not concerned. It is 25 miles long, 3 miles wide, and has a maximum depth of 2844 feet.[2]

FIG. 17.—Submerged extra-morainic channel of the Hudson.

G, shallower channel to forty-one fathom line; *H*, deeper channel. [Taken from map by A. Lindenkohl in the *U. S. Coast and Geodetic Survey Report* for 1884.]

Channel inside the moraine.—The channel inside the moraine is covered by the waters of the Hudson estuary which vary from 10 to 216 feet in depth. On the whole, the minimum depth increases from Troy to just north of Newburg. South of here the water is shallow to the Highlands. In the Highlands it is deep, and from North Haverstraw south it is shallow again, but on the whole grows deeper to the Narrows. Throughout its entire length there is a very great variation in the depth, however. There are certain "deeps" which

[1] A. LINDENKOHL, *American Journal of Science*, Vol. CXXIX (1885), pp. 475–80.

[2] LINDENKOHL, *loc. cit.*

vary from a maximum of 216 feet at West Point to 120 feet and less. (See Fig. 8 for the submerged channels near New York city.)

WAVE-WROUGHT FEATURES IN THE HUDSON VALLEY.

There is an entire absence of wave-wrought features in the Hudson Valley, so far as known, with the possible exception of some gravel ridges on the low-level delta at Fort Edward east of Glens Falls, and some indistinct terraces on the west side of the valley south of Ballston.

BURIED SOILS.

An old soil with an elevation close to sea level has been observed on the clay surface south of Hackensack. It is overlain by ten feet of sand, the lower part of which contains clay a few inches in thickness, associated with fragments of leaves and woody stems. The soil is leached to a depth of one foot.[1]

On the east side of Newark Bay, south of the Lehigh Valley Railroad, a bed of peat or peaty soil is buried by 10–30 feet of sand, much and perhaps all of which is a wind deposit.[2]

FOSSILS IN THE HUDSON VALLEY, AND IN THE LOWLAND WEST OF THE PALISADE RIDGE.

The only fossils that have been found in deposits of the Hudson water body in the Hudson Valley are: (1) Sponge spicules, fresh-water diatoms, and worm-tracks at Croton;[3] and (2) leaves of *Vaccinia oxycoccus* at Albany.[4] In the lowland west of the Palisade Ridge, near Hackensack, leaves and woody stems have been found in a bed of stratified sand and clay which underlies 8 feet of sand, containing a few gneiss bowlders, and overlies an old soil having an elevation close to sea level.[5]

[1] "Drift Phenomena of the Palisade Ridge," *Annual Report of the State Geologist of New Jersey* (1893), p. 207.

[2] *Loc. cit.*, p. 205, and GEORGE H. COOK, *Geology of New Jersey* (1868), p. 227.

[3] H. RIES, *Bulletin of N. Y. State Museum*, Vol. III, No. 12 (1895), pp. 119, 120.

[4] Described by Dr. James Eights in 1852 as probably *Mitchella repens*. Professor B. K. Emerson thinks they are probably *Vaccinia oxycoccus*, which are the most abundant leaves in the clays of the Connecticut. See *Monograph of U. S. Geological Survey*, Vol. XXIX, p. 718.

[5] "See Drift Phenomena of the Palisade Ridge," *Annual Report of State Geologist of New Jersey* (1893), p. 207.

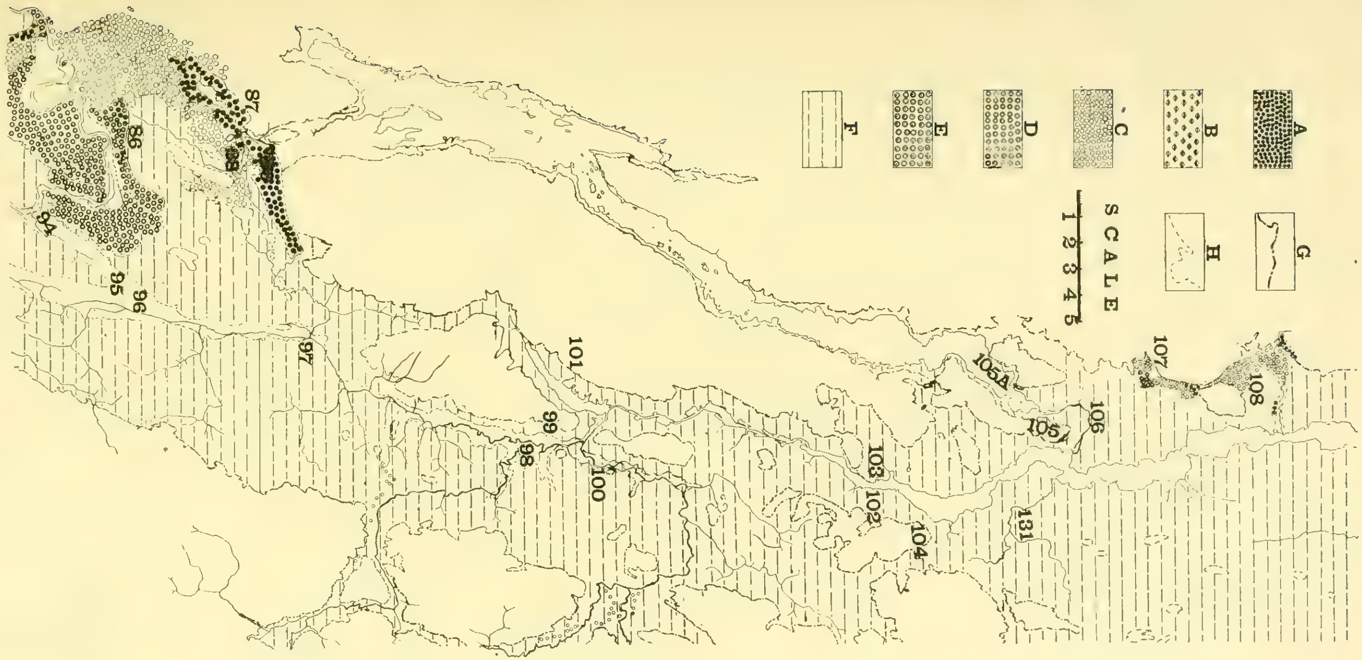


Fig. 18.—Showing known areas of stratified drift from south of Glens Falls to north of Crown Point.

Legend: *A*, moraines and kames, generally. In some places ice-shaped drift-forms that are neither moraine or kames are thus indicated. *B*, ice-molded stratified drift. *C*, gravel plateaus made by ice waters. *D* and *E*, secondary deltas. *F*, clay chiefly, but other forms of stratified drift are included. Knowledge is more certain where lines are not broken. *G*, approximate limits reached by the standing water. *H*, boundary lines showing approximate limits of the features inclosed. The white space next to the streams marks swamps, flood-plains, and low-level terraces. The heavier circles southeast of 107 and northeast of 108 show secondary deltas.

The numbers refer to the following places:

86, Glens Falls; 87, Glen Lake and Glen Brook; 88, Queensbury, Round Pond, and Jenkins Mills; 89, Hopkins Pond; 94, Fort Edward; 95, Dunham's Basin; 96, Wood Creek; 97, Fort Ann; 98, Mettawee River; 99, Whitehall; 100, Poultney River; 101, South Bay; 102, Benson Landing; 103, Putnam Station; 104, Addison-Rutland county line; 105, Mount Defiance; 105A, Baldwin; 106, Ticonderoga; 107, Street Road; 108, Crown Point Center; 131, East Creek.

WESTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.

North of Glens Falls (where the Hudson emerges from the Adirondacks) the broad lowland occupied by the Hudson ends suddenly in the rather abrupt rise of the land caused by the closing in of the highlands from the east and from the west. Through this highland there are two narrow passages—one by way of Lake George, and the other by way of Whitehall and southern Lake Champlain. These two passages are separated by highlands reaching elevations of more than 2,000 feet, and with a common elevation of 1,200–1,800 feet. This highland ends, however, in Mount Defiance near Fort Ticonderoga, and north of this place the two passages unite and broaden out into the wide valley between the Adirondacks on the west and the Green Mountains on the east, in the bottom of which is Lake Champlain. (See Fig. 18.)

The Western or Lake George Passage is a long, steep-sided, narrow valley opening out on a clay plain near Ticonderoga at the north and connecting with the Lake Champlain valley. In the bottom of this valley is Lake George, 32 miles long, and 2 miles wide in its southern, and one-half as wide in its northern part. Its greatest depth is 110 feet. At the south end of this valley there are two gaps, the western one of which has a rock-bottom at more than 500 feet A. T. The eastern and broader gap is blocked by a massive complex gravel ridge, which is a northeastward continuation of the Glen Lake kame area. (Fig. 18, No. 87.) Well data to the south of this ridge indicate a filled valley with a bottom which is lower than the deepest known part of Lake George. Through this massive gravel ridge, which obstructs the south end of the Lake George valley and is responsible for Lake George, there is a small gap followed by a tributary of Glen Brook (the outlet of Glen Lake). This tributary appears from the map to flow through a flat-bottomed valley, and one of its branches starts from a low divide at 349 feet A. T. in this valley, which separates it from streams flowing into Lake George. As will be seen later, this flat-bottomed valley may have been the outlet for a higher glacial Lake George, which existed (if it existed at all) after the ice had retreated beyond the Glen Lake kames and before it had retreated north of Ticonderoga. (See Fig. 18, No. 106.)

EASTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.

East of the highland through which is the Lake George passage the lowland of the Hudson valley is continued to Lake Champlain with a width of 5–6½ miles. The higher hilltops in this lowland are 300–400 feet below the highland farther east, and are more than double this amount below the western highland. The lower hills in the lowland have elevations of 200–400 feet lower than the higher and reach elevations of 300–520 feet.

The clay and stratified drift found in the Hudson Valley is likewise found through this lowland connecting the Hudson and Champlain Valleys. South of the Addison-Rutland county line and east of Lake Champlain it is somewhat discontinuous because of the numerous hills rising above the levels reached by the waters in which the clay accumulated. In the lower lands along the narrow part of Southern Champlain it probably was once continuous. Cut into this old clay-floor there is a valley which extends from the Hudson northward. It has two divisions which will be called the Fort Edward Valley and the Whitehall-Putnam Station Valley. These will be described presently. (See Fig. 18, Nos. 94, 99, 103.)

CHAMPLAIN VALLEY.

The lowland of the eastern passage above described extends into the Lake Champlain region, where it is found between the Adirondacks on the west and the Green Mountains on the east. It is made of the softer sedimentary rocks generally, over which are the clays and other classes of drift corresponding to those found in the Hudson Valley.

EAST SIDE OF LAKE CHAMPLAIN.

North of the Rutland county line the more hilly higher land recedes eastward from the lake shore, and from the descriptions of Baldwin[1] and some observations of the writer it would seem correct to state that the lower land near the lake is marked by a wide clay-mantled plain as far north as the Winooski, where gravel and sand deposits interrupt. It occurs again north of the gravel and sand plains of the Missisquoi River. To the eastward the clay decreases in quantity or ceases altogether, and on the higher land the drift-covered or bare rock hills cease to be mantled with the clay.

[1] *American Geologist*, Vol. XIII (1894), pp. 170–84.

Through the clay on the plain high hills rise to levels beyond that reached by the waters in which the clay accumulated. These hills are drift-covered, and the rock outcrops frequently. Other lower hills, which sometimes have the form of ridges, have rock cores, are till-covered, and are mantled by the clay so as to subdue the original irregularities of the rock and drift.

WEST SIDE OF LAKE CHAMPLAIN.

While this plain has its widest extent in the southern Champlain Valley on the east side of the lake, it has been most studied on the west side. From Ticonderoga to Port Kent the plain is not more than 3 miles wide at any point, and contracts and expands as the mountains approach or recede from the lake shore. The mountains approach close to the shore just south of Crown Point, both north and south of Port Henry, south of Whallonsburg, and north of Willsboro. They recede from the shore, near Ticonderoga, at Crown Point, from a few miles north of Port Henry, to Westport, and again from several miles south of Willsboro to a few miles north of that place. North of Port Kent the plain widens out continually to the national boundary. In its lower eastern part clay prevails at the surface, except along the streams. In the higher western part till frequently covers the surface. (See Figs. 18 and 1 for places mentioned.)

Gravel plateaus and deltas—upper and lower series.—On approach to the higher land the plain ends abruptly against the drift-covered slopes or in gravel plateaus analogous to those in the Hudson Valley. Near the rivers the plain gives place to a series of deltas and gravel ridges, which are grouped into two series—an upper and a lower, with a space of about 120 feet between the series. The upper series has a range of about 80–100 feet at the north and a greater range at the south. These gravel plateaus and deltas are, on the whole, higher at the north than at the south, but there are exceptions. Their elevations are as follows: Street Road gravel plateau, 540; delta, 320–340. Delta on Bouquet River, 460–480; 400 (?). North Branch Bouquet River near Tower's Forge, 460–80; 400 (?); near Reber, 440–60. Ausable River, 580–600 (?); 500. Saranac River, 640 (?); 520–40. The top of the Street Road 540-foot plateau may be higher than the level reached by the standing water. The lower series

of levels is made up of a succession of deltas and bar-like gravel ridges, and has a range from about 180 to 200 feet A. T. at the south, and 420 to 450 feet A. T. at the north, down to the level of Lake Champlain (101 feet above sea-level). The upper series of deltas consists of two—an upper and a lower. The upper one was made by the ice waters. The lower was made by the erosion of higher gravels. The one made in the presence of the ice may be absent on some of the more northerly streams.

Wave-wrought terraces.—Corresponding to these two series of gravel plateaus or deltas there are two series of wave-wrought terraces separated by an interval of about 120 feet at the south and 155 feet at the north. In this interval the terraces are either absent or very faint.

Upper series of wave-wrought terraces: The upper series of terraces have been seen at various points from Street Road to West Chazy. They have not been studied north of the latter place. This series of terraces has a range at Street Road and Crown Point of 200–220 feet (520–320 feet A. T.), if certain rather faint terraces be accepted as wave-wrought. The range of terraces at the north varies from 75 feet near Whallonsburg (510 –435 feet A. T.) to 80 and 100 feet farther north. On the whole the range increases northward from Whallonsburg, but is still greater at Street Road and Crown Point. Except for the fact that the upper terrace at Whallonsburg and corresponding deltas on both branches of the Bouquet River are somewhat lower than at Street Road or Crown Point, the series increases in altitude northward. Both series of terraces are best developed and have been studied most at places from Port Kent northward.

In this region the upper series of wave-wrought features is distinct, and, when one's attention has been called to it, is somewhat conspicuous. The series embraces wave-cut terraces and gravel beach ridges, and in favorable situations bars, spits, and hooks. At places where these features can best be seen they have a range of (1) about 80 feet at Port Kent; (2) 80–90 feet one-half mile west of Harkness Station; (3) 77 feet east of Mount Ætna and a little north, between the latitude of Peru and Schuyler's Falls; (4) 60 feet northwest of Peru a few miles, and nearer Schuyler's Falls than (3) above; (5) south of the Saranac River on the farm of Thomas Riley and a neighbor, the

range is 100 feet and possibly somewhat greater; (6) southwest of West Beekmantown one and one-half to two miles the range is 80 feet (600–680 feet A. T.); (7) three to three and a half miles north of the latter place, and about the same distance southwest of West Chazy, the range is 95 feet (605–700 feet A. T.). The lowest terrace of this series when projected southward connects with the bottom of the Fort Edward Valley.

Lower series of wave-wrought terraces: A gap intervenes between the lower terrace of the upper series and the upper terrace of the lower series, in which the signs of wave-action are either very faint or altogether lacking. Because the lower series of terraces is often fainter, there is some uncertainty as to the amount of this gap. At Street Road it seems to be about 120 feet; at Crown Point 100–120, and possibly 140 feet. At Port Kent this gap is 124 feet (380–504 feet A. T.). At the Saranac River it is not known exactly. It is as much as 120 and no more than 165 feet. West of West Chazy it is 155 feet. The upper part of this lower series of terraces has been examined at a few points only; namely, west of West Chazy, where distinct terraces and beach ridges range from 450 down to 400 or 380 feet A. T. Other lower levels not systematically studied are to be seen east of West Chazy. At Port Kent an extensive series of terraces and beach ridges and bars was observed to extend from an elevation of 380 feet well down toward present Lake Champlain level. There were at least thirteen levels represented. The terraces of the lower series are best brought out along the streams. They have been observed on the south side of the Saranac, where sixteen levels were observed between an elevation of 300 feet and the level of Lake Champlain. They also occur on the Salmon River. At some of these levels, low-level deltas were built. Between Port Henry and Westport the low-level terraces may be represented at several places. At Crown Point a delta level appears to be present at 180–200 feet A. T., and indistinct terraces below this level have been seen south of Crown Point.

At Street Road distinct terraces occur at 160–180 feet, and indistinct terraces are perhaps represented up to 220 feet A. T. The upper terrace of this series projected southward falls below the Fort Edward valley.

Fossils.—Below the upper terrace of the lower series of terraces marine fossils occur on the west side of Lake Champlain at the following elevations: Plattsburg, 346 feet A. T.;[1] Port Douglas, 300 feet A. T.; Willsboro, 200 feet A. T.; Port Henry, 140 feet A. T. So far as the writer knows, the last-mentioned place is the most southerly point where marine fossils have actually been found.

At South Plattsburg both marine shells and vegetation are found in a deposit of sand and silt, the top of which has an elevation of 220 feet.

SALMON RIVER SECTION, NEAR SOUTH PLATTSBURG.[2]

15. Silt.
14. Ten feet of coarse gravel, with ridge topography. The sand below the gravel ridges is eroded and replaced by coarse gravel, largely of Potsdam sandstone, but some light-colored limestone. Shells in single valves. One square-shouldered valve found.
13. Six feet of sand (and gravel?), some stratified; single valves of round-shouldered shells.
12. Fifteen to twelve feet of sand and silt with round shouldered-shells in the sand.
11. Eight feet of coarse sand; shells rare—only one found.
10. Two feet of fine sand, a three-inch layer with occasional round-shouldered shells (valves together).
9. Clay and sand; a four-inch log, two inches from the bottom of the layer; shells rare.
8. Shells and vegetation.
7. Two feet two inches of alternating sand and clay.
6. Layer of vegetation one-half an inch thick, with a fragment of a beetle.
5. One foot of sand.
4. Two feet nine inches of sandy clay; no shells, but vegetation marks.
3. Blue clay; square-shouldered shells in sandy seam with specks of vegetation four feet above the river.
2. Till; stony material, largely limestone; some purple quartzite.
1. Rock.

The layers of sand and silt are much contorted near the surface, and again not far from the base of the section. The dip is eastward at a low angle. Just a little farther downstream there are several

[1] DR. D. S. KELLOGG, *Science*, June 17, 1892, p. 341.

[2] The material found in this section has not been fully identified but is being studied. Leaves in layer 6 have been identified by Professor J. M. Coulter as belonging to some species of boreal willow. The square-shouldered shells are probably *Saxacara rugosa* and the round-shouldered shells are *Tellina Groenlandica*.

different levels of the gravel with the form of limited terraces, which are due to the slumping down of the surface as the bank has been undercut. A layer of sand containing marine shell fragments and colored by the presence of vegetation was observed west of Mooers. It underlies coarser gravel and sand. The exposure was not sufficient to allow it to be determined whether the sand with the carbonaceous material represents an old soil or is a layer like some in the Salmon River section, colored with vegetable matter.

On the east side of the lake.—Marine shells in the form of *Macoma fusca* and *Saxicava* occur at low levels. North of central Addison Township Baldwin says they are common at levels below 150 feet, and reach an elevation close to 250 feet at Vergennes. The writer was unable, however, to find any up to that level south of Otter Creek at Vergennes, and search was not made north of that place. Baldwin also reports *Macoma fusca* at Shelburne Falls and Morses in stratified sands up to 180 feet. In the northern part of Shelburne shells which from descriptions are thought to be marine are reported, he says, at 400 feet. If this is correct, it is the highest level at which they have been found. The same writer reports shells of *Saxicava* and *Macoma fusca* in the stratified sands of the 270-foot LaMoille delta at Checkerberry village, on the south shore of Mallett's Bay and in West Milton.

Bones of a whale (*Beluga Vermontana*, Thompson) were reported from Charlotte Township at 150 feet above the sea.[1] Land-snail shells have been found in high-level deposits at a number of points in the southern Champlain region a few feet beneath the surface. In one or two cases they appeared to be imbedded in the undisturbed stratified materials of wave-wrought terraces. In most cases they occur in a surface loam which has a very irregular contact with the underlying drift. A number of things connected with their occurrence in the loam point to introduction in openings made by roots of trees, but it is possible that some were buried contemporaneously with the making of the wave-wrought terraces of the upper series.

Moraines.—Above the upper series of terraces at a number of

[1] *Vermont Geological Survey*, Report in 1849, Vol. I, pp. 162–65; and DAWSON, "Cetacean Remains in Champlain Deposits," *American Journal of Science*, Vol. CXXV (1883), pp. 200–202.

points, notably (1) at Crown Point, (2) between the latitude of Harkness and the Salmon River, and (3) at Cadyville and westward toward Dannemorra, a moraine or a series of moraines with a peculiar ridge-like topography have been observed on the eastern mountain slope. At two places these moraines are situated across the course of streams in the valleys of which gravel plains occur on the upstream side of the morainic ridges, reaching to the level of their lowest part. The situation is such as to suggest the presence of local lakes in which the gravel was deposited. This point is mentioned here to call attention to the fact that the ice at this stage, at any rate, and in this part of its front, did not have the same relation to the gravel plateaus as in the upper Hudson, for apparently its edge was on the landward side and the body of ice was on the lakeward side. This appears to have been true when the Street Road gravel terrace was made, but where the ice-edge and the body of ice were at Crown Point when the highest deposits of lacustrine origin were deposited is not known. It seems difficult to reconcile the stratified drift, with its eastward-dipping layers, with the position of the ice when the moraine higher up on the mountain side was made. The deltas on the Bouquet River are so situated that it is not necessary to assume either an embayment in the ice-front or a protruding tongue of ice down the Champlain Valley. The possible 580-foot Ausable "delta" may be interpreted with either front. The Saranac high-level delta indicates the presence of the ice at its northern margin, and possibly also at its western margin; but this delta, if it be a delta, is not well known.

Below the level of the lowest terrace of the upper series a group of kames which may mark a position of the ice-edge was seen northwest of Peru, and morainic topography was likewise observed one and three-fourths to two miles west of West Chazy, between the upper and lower series of terraces.

Eskers.—An esker with a length of eight to ten miles, and with a north-by-west and south-by-east direction, is found north of the latitude of Beekmantown,[1] and a mile and a half northwest of Treadwell Bay. Its top has a maximum elevation of 240 feet and a com-

[1]This esker was first described by DR. D. S. KELLOGG, of Plattsburg. See *Science*, June 17, 1892, p. 341.

mon elevation of 220 feet. It stands 20–40 feet above its surroundings. The top is often quite flat and has been subjected to considerable wave-action. The materials are frequently coarse gravel, with occasional large bowlders. A number of wells on this esker are reported by their owners to reach clay after penetrating the gravel. Marine shells are found on the slopes of this esker a few feet beneath the surface.

The streams and their valleys.—Down the slopes of the higher land the streams extended their courses as the waters of the lake, and subsequently the waters of the sea withdrew and exposed more and more of the lake-floor and sea-floor. The courses which the streams took were determined by the slope of the land. Into their deltas the streams have cut valleys, and some have cut, not only through the delta gravels, but also through the underlying till and into the rock below. This is notably true of the Ausable River, which has reached the Potsdam sandstone at a number of places from above Keeseville to Ausable chasm. At the latter place it has cut into the Potsdam rock to a depth of 80–100 feet, causing the falls to recede from their original position at the lower end of the chasm to their present position one and an eighth miles back. The Saranac River has not only cut through the morainic ridge west of Cadyville, but through the till and into the underlying Potsdam sandstone; again to the eastward it has cut through the upper delta deposits and underlying till into the underlying sandstone. The Saranac from Cadyville downstream some distance, and the Ausable from the lower end of the chasm to some distance above, have remarkably crooked courses, with almost rectangular turns, which have been determined by the joint planes of the rock. (See Fig. 19.)

Successive stages in the downcutting of their valley-fillings are shown by a series of river terraces on the Ausable above and below Keeseville, on the Salmon River above South Plattsburg, on the Saranac above Morrisonville; and doubtless on many other streams. The successive levels of the waters of the lake and of the sea are shown on the streams by lower deltas and by lower bars and beach ridges. Some of these low-level deltas are not simple, but appear to contain glacial deposits buried in and modified by subsequent deposits. This is notably true on the Ausable.

In the southern Champlain Valley the tributaries bear evidence of recent drowning of their lower courses. North-heading streams show a recent revival, while south-heading streams show *arrested development.*

In the eastern passage to the Hudson a valley has been mentioned which will be described in two divisions as the Fort Edward Valley

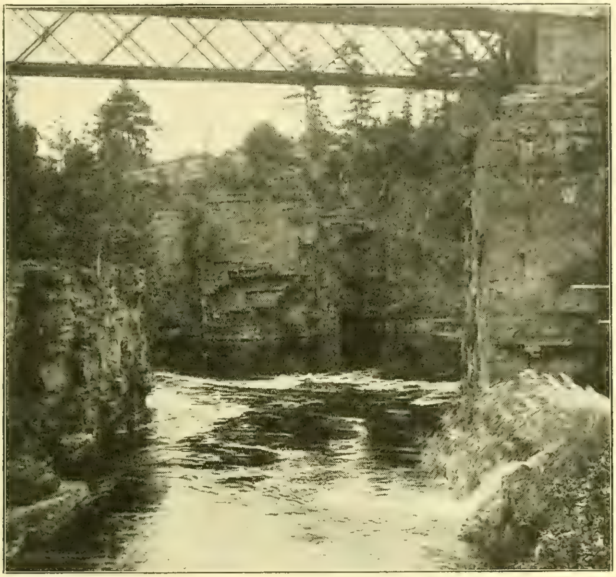


FIG. 19.—Showing the relation of the joint structure in the Potsdam sandstone to one of the rectangular turns in the Saranac River.

[Photograph by W. S. McGee.]

and the Whitehall-Putnam Station Valley. The tributaries flowing into these valleys show characteristics similar to those of the Hudson tributaries. They descend to the main valley, over steep slopes, which have been pushed farther back on the larger streams and reduced to gentler slopes than on the smaller streams, except where the rock has been encountered. This character is to be contrasted with the comparatively gentle gradients of the streams flowing into Lake Champlain farther north, where the streams lack the sudden descent at their mouths that is characteristic of those flowing into southern Champlain or into the Fort Edward Valley, except where

such descents have been produced by inequalities in the hardness of their beds. (See Fig. 16, *A* and *B*.)

Fort Edward Valley.—This valley extends from the south end of Lake Champlain at Whitehall to the Hudson River. From Dunham's Basin south it is divided into two parts. The western part ends at Fort Edward. The eastern part ends three miles farther south, and about the same distance north of Fort Miller. The narrowest part of the valley is at the edge of the highlands north of Fort Ann, where the width is one-tenth to one-fifth of a mile and the bottom is on the rock. The widest part of the valley, where the width is more than one and a half miles, is southeast of Dunham's Basin. The combined width of the eastern and western parts in the latitude of Fort Edward is nearly two miles. The bottom of the valley has an elevation, at Fort Edward, of 140 feet, an altitude which is probably considerably less than twenty feet higher than the present Hudson. The same may be said of the eastern branch of the valley three miles north of Port Miller. At Whitehall the valley bottom is 120 feet in altitude above the sea. Between these two extremes the divide, which is near Dunham's Basin, is close to 160 feet in altitude. The valley is followed by the north-flowing Mettawee River and its tributary, Wood Creek, and by the south-flowing Fort Edward Creek and Durkeetown Creek, a tributary of the Moses Kill. All these streams are very small compared with the width of the valley.

The amount of cutting of the valley is difficult of exact determination. At Fort Edward it certainly is less than 120 feet, and perhaps no more than 35 feet. In other places, on the whole, the indications are that there has been a cutting of less than 100 feet. The maximum possible cutting of the Hudson valley immediately to the southward is 160 feet, but may be only 100–120 feet.

Whitehall-Putnam Station Valley.—This valley is occupied by the southernmost and narrowest portion of southern Lake Champlain. This part of the lake, including swampy borders, has a width varying from one-tenth to seven-tenths of a mile, and a common width of one-half mile. Its sides show frequent cliffs of clay, or clay overlying silt and stratified gravel and sand, and remnants of a former valley-filling which reached, in places at least, elevations of 180–200 feet A. T. Beneath the waters of this part of the lake, and extending

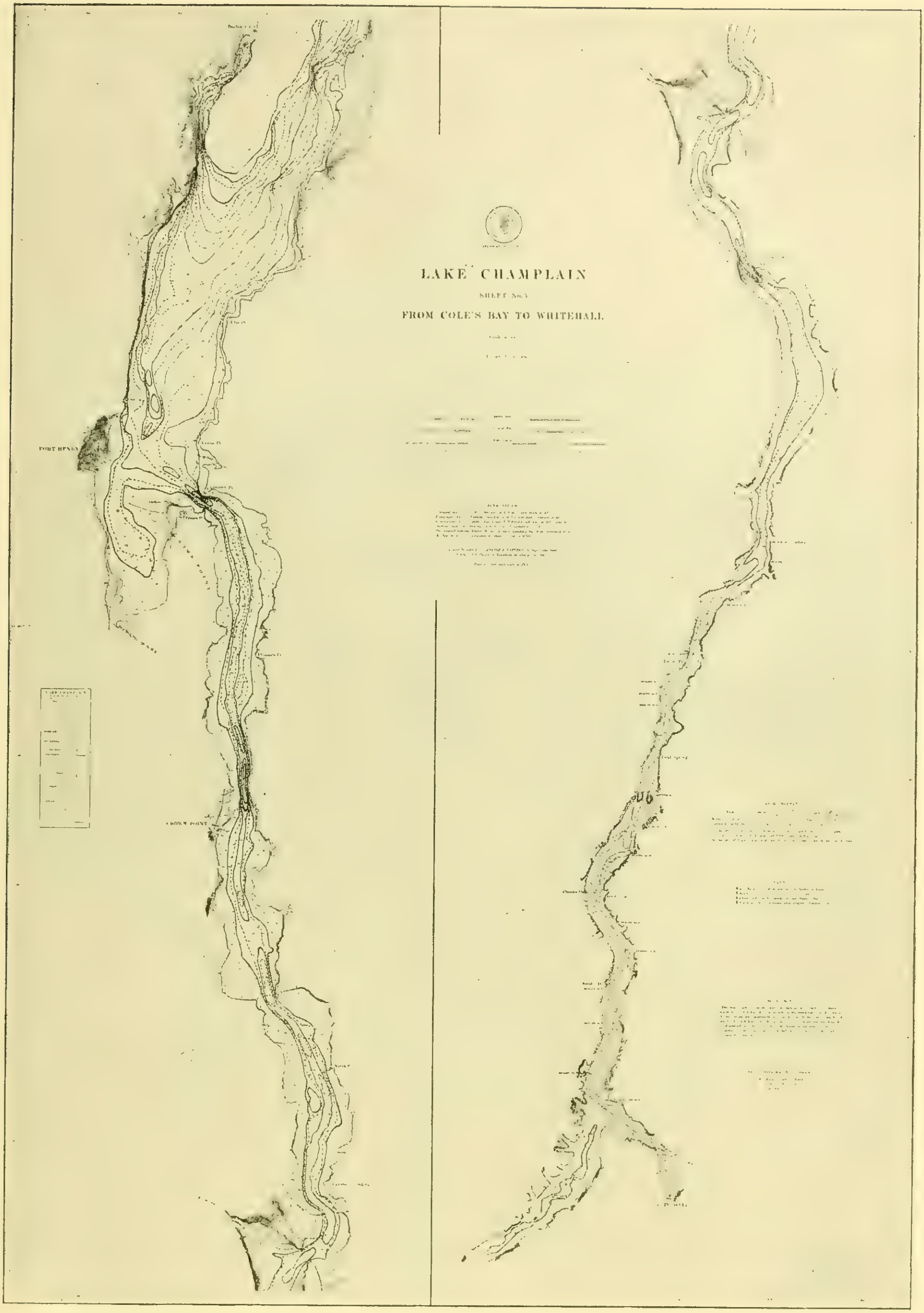


FIG. 20.—The submerged Poultney-Mettawee Valley, from Lake Survey Charts on which contour lines have been drawn. Contour interval: 5 feet, down to the ninety-foot line.

beyond it to a point five miles northeast of Port Henry, is the submerged Poultney-Mettawee Valley. (See Fig. 20.)

Submerged Poultney-Mettawee Valley.—This valley can be read from the Lake Survey charts. It occurs beneath the waters of southern Champlain from Whitehall to five miles northeast of Port Henry. The depth of water covering this valley varies from 12 to 55 feet

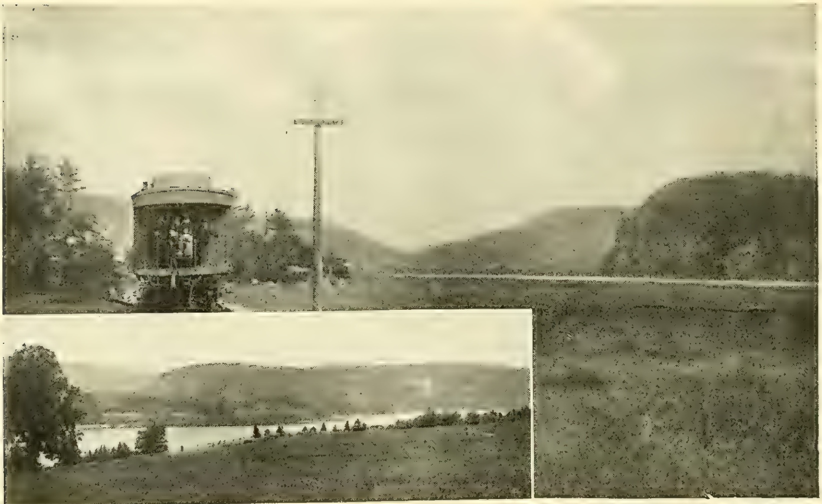


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FIG. 21.—Photograph of southern Lake Champlain, looking north near Dresden Station. Smaller view looks northwestward from Benson Landing across Lake Champlain toward Putnam Station. Beneath the waters of the lake in both views is the submerged Poultney-Mettawee Valley.

[Smaller photograph by W. S. Mc Gee.]

upstream from the delta. The outer edge of the latter is covered by water from 50 to 78 feet deep, depending on the interpretation of the edge. The depths of the valley are greatest at the narrowest parts, and the greatest depths are nearly as great at the south end of the valley as near the north end. South Bay seems to be a drowned valley partly filled, which was tributary to the main Poultney-Mettawee.

The width of the valley varies from one-tenth to one-half of a mile. Its sides are often steep, and the Lake Survey charts indicate plain areas between the cliffs which rise above the water of Lake Champlain and the tops of submerged bluffs. (See Figs. 20 and 21.)

Erosion of tributaries flowing into southern Lake Champlain.—From South Bay northward the tributaries from the west have cut valleys 40–60 feet deep below the top of the clay, and in a few cases near the lake shore as much as 60–80 feet deep. Between the valleys the points of land show cliffs furnishing numerous exposures along the Delaware and Hudson R. R. The streams on the east side of the lake are less numerous and flow down from land with a less elevation; in general, their valleys are not so extensive. Several show erosion to a depth of 40–60 feet, and perhaps one has cut as deep as 100 feet near its mouth. These figures refer to the depth of the valley above Lake Champlain level, and do not include depths below the lake-level. The lower parts of many of these tributary valleys are drowned for a distance of three-tenths of a mile from the cliff heads, and swampy bottoms farther up the valley in some cases occupy a probable former extension of the lake for five-tenths to seven-tenths of a mile.

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[*To be concluded.*]

Reviews.

The Non-Metallic Minerals. By G. P. Merrill, New York: John Wiley & Sons, 1904.

The non-metallic minerals, exclusive of gems, building-stones, and marbles, are treated in groups as elements, sulphides, oxides, etc. The nature and composition, the geological and geographical occurrence, the theories of the origin, and the uses of each mineral are presented, and in the case of the more important minerals commercially a brief description is given of the methods of mining and the preparation for the market. A valuable feature of the book to those who are making a study of special minerals is a bibliography giving complete references to articles and books on the various subjects. The occurrence of minerals, their forms of crystallization, and many other features are illustrated by numerous half-tones, diagrams, and geological sections. The author has rendered a most important service to all who are in any way interested in the non-metallic minerals by bringing together in a most concise manner much valuable information which until now was so widely scattered that it could be obtained only with great difficulty.

G. F. K.

Geology of Miller County. By Sydney H. Ball and A. F. Smith. With an Introduction by E. R. Buckley. Vol. I, Second Series. Jefferson City, Mo.: Missouri Bureau of Geology and Mines. 1903.

This is a report of 207 pages with 18 plates and sufficient figures to afford ample illustrations. Two maps accompany the report, the first one a geological map purely, and the second one an economic map showing locations of mines, quarries, clay-banks, etc. Many of the figures consist of detailed columnar sections of the different formations.

Miller county is located in the midst of the Ozark plateau, and the succession of formations is typical for most of the plateau region. The formations occurring in the county are the Proctor limestone, probably of Cambrian age; the Gunter sandstone, Gasconade limestone, Bolin Creek sandstone, St. Elizabeth formation, Jefferson City formation, and Pacific sandstone, of undifferentiated Cambro-Ordovician age; the undiffer-

entiated Jefferson City and Coal-Measure shale, Burlington limestone, Graydon sandstone, Saline Creek conglomerate, and coal and Coal-Measure shale, of Carboniferous age; and the alluvium, of Pleistocene age.

The field-work on the report under review was begun in November, 1901. At that time there were forty-nine counties for which reports and maps had never been issued; forty-nine counties for which general reconnoissance reports had been published; one for which a complete detailed report had been published; and twenty parts of counties for which detailed reports had been published. It is the purpose of the Survey to issue reports in detail upon the forty-nine counties for which no reports have been published, and under this scheme the report on Miller county is the first to appear, although the field-work has been done in two other counties. County reports are to be issued in preference to sheet reports, because it is the belief that they serve better the interests of the citizens of the state. It is the general plan of the Survey to extend the county surveys to the southwest, southeast, northeast, and northwest, thereby connecting with the surveys of the lead, zinc, and coal fields of the state.

In the *Geology of Miller County* all phases of the subject are discussed in considerable detail. In the chapter on the physiography of the region the different types of surface relief are first described, and the relations of physiographic types to industrial and social conditions are set forth in a brief but very interesting way. The major portion of the report is then taken up with careful descriptions of the different geological formations, dealing with their areal extent, thickness, bedding, weathering, composition, texture, relations to adjacent formations, porosity, color, fossils, topography, etc. A chapter is devoted to a discussion of structure, with folding and flexing, faulting, jointing, and unconformities as sub-headings. Another chapter deals with the origin of chert and dolomite. The final chapter is given over to economic considerations, and consists of descriptions of the manner of occurrence, origin, and other characteristics of barite, building-stone, clay, coal, iron, ore limestone, lead, and zinc, road materials, sand, silica, soils, etc.

The Geological Survey of Missouri has been in existence for a good many years and has issued some excellent reports. It has done a notable service to the people of the state, and to it also the geologists of the country are indebted. The volume just issued will be of great value to the citizens of Miller county, and will be well received by all persons without the county who are interested in geology. The report is written in such a way that it can be used in the public schools of the state, and is hence of direct educational value. It is so complete in its treatment of the subject that another

report upon the county will not be needed for many years. A topographic map would have increased the value of the report, and no doubt the reader without the state who is unfamiliar with Missouri geography (as is the case with the reviewer) would appreciate a small index map showing the exact location of Miller county. It is a source of regret that where the matter has been so well prepared the proof-reading should have been so carelessly done, and that the proportion of misspelled words should be so large as a necessary consequence.

H. L.

THE

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SEPTEMBER-OCTOBER, 1904

PHYSIOGRAPHIC STUDIES IN SOUTHERN PENNSYLVANIA.[1]

CUMBERLAND VALLEY is the northward extension into Maryland and Pennsylvania of the Shenandoah Valley of Virginia. It is a broad limestone valley, with low, shale hills, lying between South Mountain on the east, and Tuscarora Mountain and associated ridges on the west. The southern portion is drained chiefly by Conococheague and Antietam creeks into the Potomac, and the northern part by Conodoguinet and Yellow Breeches creeks into the Susquehanna. The area discussed in this paper is that portion of the Cumberland Valley and bordering mountains which is represented on the Mercersburg and Chambersburg, Pa., atlas sheets of the U. S. Geological Survey, on the scale of 1 mile to 1 inch. Fig. 1 is a contour map of the same area.

Conococheague Creek, which enters the Potomac at Williamsport, Md., divides into two branches in the southern part of this area. The West Conococheague heads in Tuscarora Mountain to the northwest, and enters the main valley from Path Valley. The East Conococheague reaches the valley through a narrow gap in South Mountain in the eastern portion of the area, and after flowing northward for 5 miles, turns southwestward. Before uniting with the west branch it is joined by another prominent stream, Back Creek, which drains the northern part of the area.

It has been pointed out by Campbell[2] that two, and possibly three,

[1] Published with the permission of the director of the U. S. Geological Survey.

[2] "Geographic Development of Northern Pennsylvania and Southern New York," *Bulletin of the Geological Society of America*, Vol. XIV, pp. 277–96.

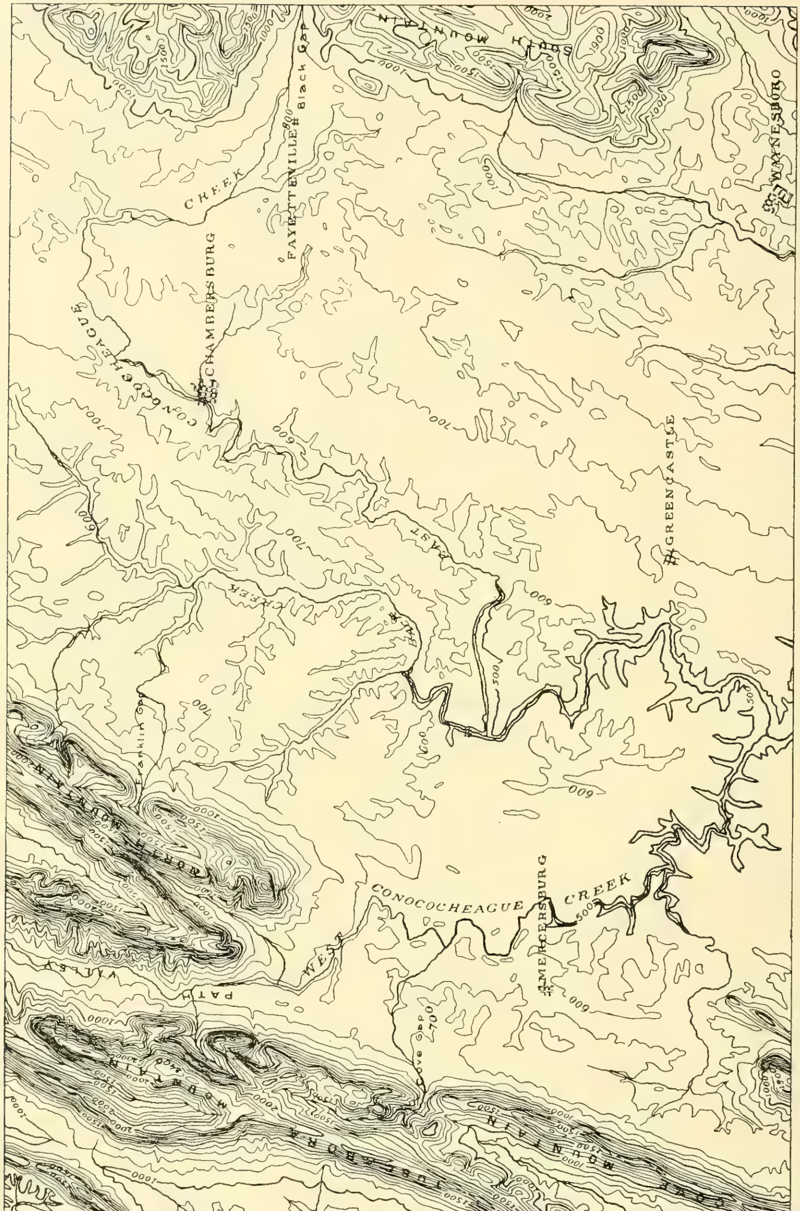

FIG. 1.—Contour map of the Mercersburg and Chambersburg quadrangles, Pa.
Scale: 1 inch = approximately 4.2 miles. Contour interval 100 feet.

peneplains exist in this area, and similar features in the adjacent portions of Maryland have been described by Abbe.[1] The mountains rise abruptly out of the valley 1,000 to 1,500 feet. The western range consists of a series of parallel ridges composed of quartzite and sandstone of Medina and Clinton age. The crests of these ridges form a very even and level sky line, which suggests at a glance that they are remnants of an old peneplain. As one approaches from the east North Mountain comes first into view, but extends into the area only about 6 miles. It is a double or canoe-shaped mountain, ending at the south in Parnell Knob. It is a closely folded syncline of quartzite, inclosing overlying shale in the center. The rocks are nearly vertical, and the quartzite ridges are consequently narrow and sharp. Although at a distance their tops fall in line with the crests of the more distant ridges and present a level sky line (see Fig. 2), on closer examination irregularities appear. The eastern limb of the syncline is cut through by water-gaps at several points, and its original height has been reduced so that the crest is irregular. Its highest points are slightly over 1,800 feet. The western limb is more even, but is cut by a wind-gap at the southern end. Its top lies between 1,850 and 1,950 feet elevation, except near the northern border of the area, where it is locally 2,040 feet. At the southern end of the syncline two knobs, whose summits are broad and rounded, rise to 2,000 feet, and they may well represent portions of the old peneplain but slightly eroded.

The next ridge to the west is another canoe-shaped mountain, less compressed than the North Mountain syncline. It ends in Jordan Knob, a companion peak to Parnell Knob, and extends about the same distance into the quadrangle. The eastern limb of this fold is very steep and the ridge narrow and sharp-topped. In the western limb the dips are flatter and the mountain is broader and more massive. The eastern ridge has an altitude of about 1,950 feet. The general altitude of the western ridge is about 2,000 feet, but the highest peak rises to an altitude of 2,250 feet near the northern boundary of the quadrangle. The higher summits of this ridge are rounded, and in this respect possess the characteristics of an old

3 "Physiography of Maryland," *Maryland Weather Service*, Vol. I, Part 2, pp. 157–61.

peneplain, whereas the intervening portions of the ridge are reduced to a sharp crest.

To the west is a group of ridges striking entirely across the area and forming the main mass of this western range. At the north the structure is complex and the ridges are irregular. To the south the mountain is composed of two distinct monoclinal ridges, with a deep, broad, synclinal valley between. The eastern limb, forming Cove Mountain, is vertical, and has been weakened by faulting, so that the summit is a knife-edged crest of jagged quartzite beds. Although

FIG. 2.—North Mountain from the plateau west of Chambersburg.

some of its highest points reach 1,800 feet, its average height is between 1,600 and 1,700 feet, and its crest has a decided wavy or comby appearance. Just beyond the southern border of the quadrangle this ridge swings to the east, across the end of a flat anticline, in what is known as Cross Mountain, and then extends northward again a short distance as Two Top Mountain. From the valley one observes an abrupt change from the low, comby crest of Cove Mountain to the uniform, level crest of Cross Mountain (see Fig. 3) which has an altitude of about 2,000 feet. It is apparent that Cove Mountain once stood at approximately this altitude, but has been lowered by the active erosion of the relatively narrow exposure of upturned rocks. The broad mass of gently dipping strata in the anticline of

Cross Mountain has resisted erosion, and its flat, broad top is probably a remnant of the old peneplain surface.

Northward beyond Cove Gap the structure of Cove Mountain is synclinal, but is complicated by faulting. Although some of its summits rise to 2,050 feet, its general elevation is not over 1,800.

The western monoclinal ridge, Tuscarora Mountain, is more massive than Cove Mountain because the rocks are not so steeply inclined and have withstood erosion better. Consequently it has a greater altitude, ranging from 1,950 to 2,050 feet, and a smoother

The middle-ground is the gently rolling upland north of St. Thomas.

crest line. Northward this monoclinal mountain forks by the development of a synclinal valley and another monoclinal ridge on the western side, the eastern ridge becoming anticlinal for a short distance. The anticlinal portion of the ridge is 2,450 feet in elevation, and is very broad and flat-topped. From its summit one looks over the tops of the other ridges, whose general level is 300 and more feet lower. It is evident that this peak was a monadnock in the old peneplain. Its broad, rounded character is due to its partial reduction to the graded plain. Northward the eastern limb of the anticline is faulted off and the ridge continues as a monocline at about 2,250 feet elevation.

The monoclinal ridge, which branches off to the west, has an

average elevation of 2,100 feet, but rises to the height of the anticlinal ridge near their junction. The rocks become steeper toward the north, and the ridge contracts correspondingly in size and altitude.

South Mountain, on the east side of the valley, is more massive than the western range. The strata composing it are several thousand feet of interbedded Cambrian quartzites and shales, overlying older volcanics. The quartzites form the higher ridges, and the shales and volcanics are covered by a thick mask of the quartzite bowlders which prevent the erosion of deep valleys. The ridges are not straight, parallel, and even-topped like those of the western range, but are offset by cross folds and faults, and are cut through by transverse drainage, so that the crest is composed of numerous round-topped, elongate knobs and short ridges. Consequently they do not present so level a crest line as the western range.

In the heart of the mountains extending beyond the eastern border of the Chambersburg quadrangle, two high and very level tracts occur. Sandy Ridge and Snowy Mountain, southeast of Montalto, are broad and level-topped, and have a general altitude of about 2,000 feet, with a small knob rising to 2,100 feet. They are composed of nearly horizontal quartzite, forming the flat top of the anticlinal uplift of South Mountain. The other tract is Big Flat, occupying a large area on the top of the mountains northeast of Fayetteville. This also is the flat crest of an anticline developed to the west of the main axis of the mountain, and producing a prominent offset in the mountain front opposite Fayetteville. This plateau extends for 7 or 8 miles beyond the limits of the quadrangle at a general altitude of 2,000 feet, attaining an elevation of 2,100 feet at two points. These two level tracts are undoubtedly remnants of the old peneplain, preserved at a height of 2,000 feet. The monoclinal ridges along the front of the mountain, which once stood at this same altitude, have been reduced by erosion to 1,700 and 1,900 feet.

This peneplain, observed in both South Mountain and the Tuscarora Mountain group, has long been recognized in this part of the Appalachians, and has been described by several geologists. Davis[1] named it the Schooley peneplain from its characteristic development on

[1] "Geographic Development of Northern New Jersey," *Proceedings of the Boston Society of Natural History*, Vol. XXIV, p. 377.

Schooley's Mountain, N. J., and Willis[1] later called it the Kittatinny peneplain after the mountain of that name. It has been traced eastward under the deposits of Cretaceous sediments on the eastern border of the continent, and is therefore shown to have been formed by aërial erosion while the land stood approximately 2,000 feet lower than at present. The plain extended over the present Cumberland Valley, where its surface was composed largely of limestone and shale,

FIG. 3.—The Schooley peneplain preserved on Cross Mountain in the center, with the lower comby ridge of Cove Mountain on the right.

but in part, probably, of overlying quartzites. These rocks have been removed during subsequent uplift and erosion. The resistant quartzites forming the mountains have withstood erosion, and rise approximately to the level of the former peneplain. The present altitude of the plain in South Mountain is about 2,000 feet, and in Tuscarora and associated mountains from 2,000 to 2,100 feet, which may indicate that in the uplift there was tilting toward the southeast.

At lower altitudes in the mountainous areas there are broad, flat, terrace-like features, which probably represent prolonged stages of erosion during local halts in the elevation of the land. A broad flat

[1] "The Northern Appalachians," *National Geographic Monographs*, Vol. I, p. 189.

3 miles in extent occurs at 1,600 feet elevation in the heart of South Mountain east of Montalto, and another at 1,350 feet elevation at Monterey, near the state line. Both of these are cut in the softer, ancient volcanic rocks underlying the quartzites. There are also numerous broad, flat divides at elevations from 1,450 to 1,750 feet. A broad gap near the southern end of North Mountain, at an elevation of 1,550 feet, represents the abandoned outlet of the stream which formerly flowed longitudinally along the North Mountain syncline at this altitude, but was captured by Wilson Run at Franklin Gap. In Path Valley the shale spurs extending out from the mountain on the east are roughly terraced, two of the most prominent benches lying at 1,100 and 1,200 feet. Cowan Gap, in Tuscarora Mountain, through which Little Aughwick Creek formerly flowed into Path Valley, is a broad gap at 1,200 feet. Correlation of these features has not been attempted.

Mr. Campbell, in his article on the Geographic Development of Northern Pennsylvania and Southern New York,[1] states that throughout the great valley (which includes the Cumberland Valley) the limestones which occupy the southeastern side are eroded deeper than the shales which occupy the northwestern portion. This is not the case in the Mercersburg-Chambersburg quadrangles and adjacent areas. The rocks in the eastern portion of the valley are the lower members of the Cambro-Ordovician limestone, and contain many hard, siliceous beds and several resistant sandstones. Some of these produce prominent hills from 750 to 850 feet in altitude, a few rising to 900 and 1,000 feet. The upper beds of the limestone series, however, are purer and dissolve more readily, so that in the central portion of the valley adjacent to the areas of overlying shale the surface is uniformly lower. Out of this lowland the shale hills rise abruptly, with steep escarpments, forming what may be called low plateaus.

There are two main belts of shale in the Mercersburg-Chambersburg quadrangles: one west of Chambersburg and Greencastle, which crosses the quadrangles from north to south, and is cut longitudinally by East Conococheague and Back creeks; the other a smaller north and south belt in the vicinity of Mercersburg. These hills, or plateaus, are in general very level-topped (see Fig. 2), although the

[1] *Loc cit.*, p. 283.

rocks composing them are broadly folded and sharply plicated, and vary from fissile shale to soft but tough sandstone, which are alike planed off.

The northern portion of the larger shale belt, lying between East Conococheague and Back creeks, is the highest of the shale tracts. It is a narrow plateau extending from the junction of the two creeks to beyond the northern limits of the quadrangle. Along its axis it has a nearly uniform elevation of 750 feet, but rises at one point in the north to 780 feet, and decreases to 700 feet near its southern apex and on its margins. It has been considerably dissected along its borders, especially on the western side, where the tributaries of Back Creek have trenched it deeply, but the intervening spurs still retain their level character and to some extent their original height. The descent from the plateau level to the stream bottoms on either side is very steep and abrupt. This is especially pronounced on the east side, where the valley is a limestone lowland. On the west the shale tract extends beyond Back Creek, and the plateau character continues at a somewhat reduced altitude, but attains 720 feet elevation at the northern border of the quadrangle.

There are no other extensive level tracts at this altitude in the area, but there are several scattered terraces and hilltops which approximate this height. West of Mercersburg, near Cove Mountain, the shale hills rise to 700 feet, and a little farther north, where an intermontane stream debouches at Cove Gap, an apron of mountain rock has been spread over these hills at an altitude of 740 feet. The same is true of a small 720-foot terrace just east of Fort Loudon, which was covered by mountain wash from Bear Valley when its outlet was at this altitude. Another hill covered with water-worn gravel occurs at Franklin Gap in North Mountain, the outlet of Wilson Run. This, however, has an altitude of 800 to 820 feet. The east branch of Little Antietam Creek, which occupies a re-entrant valley in South Mountain in the southeast corner of the area, has bowlder-covered terraces on both sides of the stream at 760 feet elevation. A similar but more extensive level tract covered by quartzite bowlders, occurs at Black Gap, in South Mountain, where the East Conococheague leaves the mountains and enters the valley. Here a very level plain extends for four miles along the creek at an elevation of 840 feet.

Nowhere on its surface is bed rock exposed, and only one or two outcrops were found in stream cuttings on its borders, indicating a deep deposit of stream wash. In the limestone area on the eastern side of the valley there are numerous hilltops which approximate 740 to 760 feet in altitude, but many rise higher, and there is no apparent uniformity

It is clear that the valley in this region was once a nearly level plain, which has been deeply eroded, leaving remnants at approximately 700 to 750 feet elevation. Campbell[1] has described a peneplain preserved throughout this region on the shale at approximately this altitude. He has named it the Harrisburg peneplain from its typical development at Harrisburg, Pa., and assigns to it an early Tertiary age. It seems strange that the peneplain should be preserved in the Chambersburg plateau, which is exposed to such active erosion from tributaries of two large creeks, whereas in more favorable areas only small remnants remain, but this is probably due to a soft but tough sandstone which is locally interbedded and infolded in the shale of this hill and has aided in its preservation. Nearly all the other areas occurring at this altitude were protected by a covering of stream gravels. At Black Gap the gravel-covered plain has a uniform altitude of 840 feet. The capping of gravel and cobble, judging from the nearest bed rock observed, is about 60 or 80 feet thick. East Conococheague Creek, which issues from the mountains at this point, is a large stream and drains a considerable portion of the mountains to the east. On leaving its confined channel in the gap and entering the open plain its velocity would be slackened, its transporting power lessened, and a portion of its load of mountain rock would be dropped. In this way a delta has been built up 60 or 80 feet above the general level of the peneplain. The great extent and level character of this delta bears evidence of a prolonged halt in the uplift of the land and of active erosion on the headwaters of the stream. The delta at Franklin Gap, which also stands at 800 to 840 feet elevation, was similarly built up above the plain. Other local delta gravels at about this height occur at smaller gaps along the mountain front. In Path Valley two well-marked terraces on the shale at 820 feet may represent this stage but at a higher level in the narrow tributary valley.

[1] *Loc. cit.*, pp. 283–91.

The larger streams have very meandering, tortuous courses, not due to present aggraded conditions, since they occupy deep gorges in the broad shale areas and their grade is about 100 feet in 6 to 10 miles air line. These crooked streams originated on a graded plain, an additional evidence of the existence of a peneplain at about the Harrisburg level, and this mature drainage was rejuvenated by uplift and cut deep, sinuous valleys. The spurs between the bends of the streams in the shale areas are terraced at various levels, ranging in altitude from 580 to 680 feet. Many of the terraces and slopes along East and West Conococheague creeks are covered with quartzite bowlders transported from the mountains by these streams during the cutting of the gorges, but no such deposits have been found on the surface of the Chambersburg plateau.

As to the presence in this area of a lower peneplain of later Tertiary age equivalent to the Somerville peneplain of Davis, as suggested by Campbell,[1] the evidence is not so clear. Along both Back Creek and East Conococheague Creek terraces at 680 feet are very conspicuous, and the shale plateau near St. Thomas also attains this altitude. To the south the level tops of the central shale belt are all at 600 to 620 feet, and in many cases this altitude is maintained to the ends of the spurs between the creek bends. Other spurs have been lowered to 580 and 560 feet. At Upton the 600-foot plain is very pronounced and extends several miles on to the limestone area to the northwest. In the western shale belt the upland is at 600 to 620 feet elevation, with a few higher tables previously mentioned nearer the mountains. The limestone tracts adjoining the shale have in general been reduced to a rolling lowland about 550 to 560 feet in altitude, which probably indicates a more recent epoch of erosion affecting these soluble rocks. The limestone area along East Conococheague Creek from Chambersburg south, however, stands at 600 to 620 feet elevation, forming a very level tract covered largely by stream gravel.

Of these later erosion features the most marked is the 600-foot plain which forms plateaus of relatively wide extent and level character. This, if any, represents the lower peneplain of late Tertiary age which Campbell correlates with the Somerville plain of Davis. The

[1] *Loc. cit.*, p. 287.

680-foot terrace probably represents an earlier halt of short duration and the 560-foot lowland a very recent broadening of the limestone valleys.

There are recognized in this area, therefore, the Schooley peneplain at 2,000 to 2,100 feet elevation forming the mountain summits, the Harrisburg peneplain at 750 feet on the higher shale hills, a peneplain at 620 feet on the lower shale hills possibly equivalent to the Somerville plain of New Jersey, and intermediate uncorrelated terraces at various levels.

George W. Stose.

Washington, D. C.

ÜBER DIE GEGENSEITIGEN BEZIEHUNGEN ZWISCHEN DER PETROGRAPHIE UND ANGRENZENDEN WISSENSCHAFTEN.[1]

In wenig anderen Naturwissenschaften haben seit dem letzten Drittel des vorigen Jahrhunderts so tief eingreifende Veränderungen Platz gegriffen, wie in der Petrographie; erst in den jüngsten dreissig oder vierzig Jahren sind jene feineren Untersuchungsmethoden ersonnen, ausgebaut und fruchtbar gemacht worden, denen sie einen Theil ihrer heutigen Gestaltung verdankt, vor allem die Herstellung der Dünnschliffe, die Benutzung des Mikroskops sowie die Verwerthung anderer optischer Instrumente. Und mit dem Maass der dadurch gewonnenen neuen thatsächlichen Erkenntniss wuchs auch das Bestreben, unter Berücksichtigung geologischer Beobachtungen die Einsicht in den causalen Zusammenhang petrographischer Erscheinungen und in genetische Verhältnisse zu vertiefen, mit dem Descriptiven das Speculative zu verbinden. Im Verlauf jener Zeit ist nebenbei die Anzahl der Forscher auf diesem Gebiete ganz ausserordentlich gestiegen, zum Theil in Folge der Anregung und Unterstützung, welche die inzwischen neu errichteten Institute darboten, während die Aufsammlungen und Arbeiten der geologischen Landesanstalten das Untersuchungsmaterial ins Ungemessene vermehrten. Die petrographische Literatur, vordem ausser in Deutschland fast nur in England, Frankreich und Skandinavien gepflegt, hat einen sozusagen internationalen Charakter angenommen und die Vereinigten Staaten sind, nachdem einmal eine Schaar ausgezeichneter junger Gelehrten in Europa Ausbildung und Interresse gewonnen hatte, durch selbständige und unabhängige Weiterarbeit mit in die allererste Reihe getreten.

Es gibt gar keine Wissenschaft, welche für sich ganz allein, ohne passive oder active Beeinflussung bestehen könnte; wie sie alle zu ihrem Ausbau die Aufnahme von Ergebnissen verwandter Disciplinen bedürfen, so spendet auch jede wiederum von ihren eigenen Resultaten etwas zur Förderung anderer.

[1] Address presented at the International Congress of Arts and Science, Universal Exposition, St. Louis, September 22, 1904.

Wenn die Petrographie sich mit dem Material, welcher die äussere feste Erdkruste zusammensetzt mit den Gesteinen, beschäftigt, so ist es nicht zweifelhaft, dass Mineralogie und Geologie, Physik und Chemie die zunächst verwandten und solche Wissenschaften sind, welche im Dienste der Petrographie durch friedliche Assimilation selbst zur Petrographie werden, wie jeder Stein, den man zum Gebäude benutzt, dadurch ein Baustein wird, mag man ihn sonst noch nennen, wie man will.

Handelt es sich um die beiden Fragen: erstlich, was alles tragen die benachbarten Wissenschaften zum Ausbau der Petrographie bei, und zweitens, was vermag umgekehrt die Petrographie aus dem Umfange ihrer eigenen Erfahrungen abzugeben, um auf angrenzenden anderen Gebieten Verständniss von gesetzlichen Erscheinungen zu schaffen oder die Lösung von Problemen anzuregen, so scheint es, dass unsere Wissenschaft wohl im Ganzen mehr als Empfängerin, denn als Geberin dasteht, wenn auch nicht in demselben Maasse genährt und unterstützt, wie es bei jenem grossen Complex von heterogenen Disciplinen der Fall, den man die moderne Geographie nennt.

In einer Beziehung liegt die Sache freilich ganz anders, bei dem Verhältniss der Petrographie zur *Mineralogie*. Jeder, der in den letzten Jahrzehnten auf beiden Gebieten thätig war, oder gar, wie es bei mir zutrifft, auch den modernen Aufschwung der Petrographie noch mit erlebt hat, wird zugeben, dass für speciell petrographische Zwecke unternommene Studien unendlich mehr mineralogische Frucht getragen haben, als es umgekehrt der Fall. Zwar waren in den fünfzigen Jahren schon vereinzelte zusammenhanglose Versuche gemacht worden, isolirte Mineralien mit dem Mikroskop zu betrachten, Versuche aber, die bei der damals herrschenden Gleichgültigkeit, Verständnisslosigkeit oder Skepsis sozusagen ohne jede weitere Bedeutung blieben. Die methodische und verallgemeinerte mikroskopische Untersuchung der Mineralien hat jedoch erst bei den Dünnschliffen derjenigen eingesetzt, die eine Rolle als Gemengtheile von *Felsarten* spielen und in deren Erkenntniss der Hauptaufgaben der Gesteinskunde beruht, so dass alle diese Forschungen in viel grösserem Maasse um specifisch petrographischer als um specifisch mineralogischer Zwecke willen unternommen worden sind. Und alles,

was nun für die *Gesteins*mineralien mit wachsendem Eifer festgestellt wurde; die Lage der optischen und Elasticitätsaxen in ihnen, die Brechungsquotienten und die Absorptionscontraste, die Cohäsionsverhältnisse, die Gesetze ihrer Zwillingsbildungen und die Beschaffenheit ihrer feineren Structur, die Natur der in ihnen enthaltenen festen und flüssigen mikroskopischen Einschlüsse, die Erscheinungen der Zersetzung und Verwitterung, die Umbildung in neue epigenetische Substanzen—alles dieses ist nun auch der eigentlichen Mineralogie zu Gute gekommen. Auf die Entwickelungsgeschichte zahlreicher Mineralien ist erst Licht gefallen, als man veranlasst war, die *petrographischen* Vorkommnisse derselben zu studiren. Wie spärlich waren, bevor die Gesteinskunde sie in ihr Bereich zog, unsere Kenntnisse von Titaneisen, Sillimanit, Cordierit, Zoisit, Tridymit, über Nephelin, Leucit, Melilith und viele Feldspatharten, über die Glieder der Pyroxen-Amphibolgruppe; wie dürftig würden die Lehrbücher der Mineralogie erscheinen, wenn alles aus ihnen hinweggenommen wäre, was auf Grund von petrographischen Arbeiten jetzt ihren Inhalt bereichert und anziehend macht. Jene petrographisch-geologische Theorie, durch welche Bunsen die verschiedenartige chemische Zusammensetzung der eruptiven Felsarten erklären wollte, spiegelt sich wieder in der geistvollen und fruchtbringenden Auffassung Tschermak's von dem Aufbau der triklinen Feldspathe aus zwei chemisch differenten aber isomorphen Endgliedern.

Dass bei allen diesen mineralogisch-petrographischen Studien *physikalische* Methoden unausgesetzt zur Geltung kommen, versteht sich von selbst. Wenn aber auch so die optisch-physikalischen Instrumente zum Gemeingut der Petrographen geworden sind, so sollte nicht übersehen werden, dass die Letzteren für ihre speciellen Zwecke gewisse derselben eigens ersonnen, an anderen werthvolle Verbesserungen angebracht haben, was Alles wieder der eigentlichen Physik zu Gute kommt. Und sodann, dass ein beträchtlicher Theil der optischen und thermischen Gesetze überhaupt erst ergründet oder bestätigt werden konnte an Objecten, die dem Steinreich entstammen. Das physikalische Verfahren bei der Fractionirung heterogener Gemenge mittels schwerer Flüssigkeiten ist durch seine Anwendung auf petrographischem Gebiet jetzt hoher Vollendung

entgegengeführt worden. Nur zum Theil petrographischer, vorwiegend geologischer Natur sind die Untersuchungen, welche sich bestreben, die Gesetze der Mechanik anzuwenden auf das Gesteinsmaterial, welcher einer Deformation, Torsion, Zerreissung anheimfiel.

Schon sehr lange besitzen wir *chemische* Bauschanalysen von Gebirgsarten, ferner sog. Partialanalysen der in Säuren löslichen oder zersetzbaren und der davon unangegriffenen Antheile, Analysen der enizelnen isolirten Gesteinsmineralien, wenn alles dies auch anfangs vielleicht nur mehr als ornamentale Verbrämung der Gesteinsbeschreibung betrachtet und vielfach von wenig erfahrenen Novizen unternommen wurde, dann auch eine Periode der Vernachlässigung eintrat, wo das rapid wachsende Studium der Kohlenstoffverbindungen als ein verlockenderes und möglicherweise finanziellen Gewinn bringendes Gebiet erschien. Augenblicklich ist die Anwendung der *analytisch-chemischen* Untersuchungsmethoden auf das petrographische Material, in ihrer unabweisbaren Bedeutung nicht hoch genug anzuschlagen, mehr denn je zur Geltung gekommen, und wie von jeher stehen mit Recht die massigen Eruptivgesteine und die Krystallinen Schiefer im Vordergrunde des Interesses. Ja, in den letzteren Jahren scheint man gar in der Berücksichtigung der chemischen Specialitäten dann zu weit zu gehen, wenn man auf Grund von geringfügigen Differenzen unter den einwerthigen oder unter den zweiwerthigen Metallen oder zwischen beiden gleich Veranlassung nimmt, neue belastende Namen für diese überhaupt nicht stöchiometrisch zusammengesetzten Gesteinsmassen aufzustellen.

Höchst werthvolle und zahlreiche Einzelbeiträge sind jetzt im Laufe der letzten Zeit auch von Seiten der U. S. Geological Survey geliefert worden, viele Hunderte von Analysen nach immer mehr vervollkommneten und den strengsten Anforderungen genügenden Methoden, nach Methoden, die auch gezeigt haben, dass als äusserst selten geltende Stoffe, wie Vanadin, Baryum, Strontium, sich in den meisten oder fast allen Eruptivgesteinen finden, Molybdän zwar sehr spärlich, aber unerwartet häufig. Hier ist vor allem der Name des verdienstvollen Hillebrand zu erwähnen, dessen "Praktische Anleitung zur Analyse der Silicatgesteine" einen förmlichen Schatz von Erfahrungen und Fingerzugen enthält. Sehr richtig hob er hervor, vie wünschenswerth eine Wechselwirkung zwischen chemischer

und mikroskopischer Untersuchung sei, die beide häufig noch getrennt ausgeführt werden und dass, wenn das Studium der Dünnschliffe allemal den Analysen vorausginge, die letzteren viel leichter und exacter erledigt würden.

Die chemisch-petrographische Literatur ist jüngst um ein wahrhaft grossartiges Werk bereichert worden, was ebenfalls diesseits des atlantischen Oceans mit bewundernswerthem Fleiss ausgearbeitet wurde. Henry Washington hat es, ein Nachfolger von Justus Roth, aber von moderneren Gesichtspunkten ausgehend, zu Wege gebracht, alle in den 16 Jahren von 1884–1900 veröffentlichten Analysen von Eruptivgesteinen und Tuffen zusammenzustellen und kritisch zu verarbeiten; neben den einleitenden Bemerkungen über Auswahl der Objecte, Materialmengen, Maass der Genauigkeit und der Ausführlichkeit, Irrthumsquellen u. s. w. ist vor allem wichtig der erste Versuch, den Werth der Analysen gerecht und unbefangen zu taxiren: von ähnlichen Erwägungen aus, nach denen der Credit eines kaufmännischen Geschäfts beurtheilt wird, unternimmt er es, im Hinblick auf den Grad der Exactheit und der Vollständigkeit, die Analysen in 5 Gruppen zu bringen, welche in absteigender Folge die Praedicate: excellent, good, fair, poor, bad erhalten, ein sehr dankenswerthes Beginnen, hoffentlich zugleich ein Mahnrüf an die Analytiker.

Bei der Veranstaltung chemisch-petrographischer Analysen handelt es sich einmal darum, überhaupt die Zusammensetzung einer Felsart festzustellen, sowohl um die procentarische Betheiligung der verschiedenen Stoffe daran zu erkennen, als auch eine Einsicht in die Stellung zu gewinnen, welche das Vorkommniss innerhalb gewisser chemischer Reihen einnimmt. Während in einem normalen Verbande sich ein constantes Steigen und Fallen der Stoffe geltend macht, sind in dieser Hinsicht namentlich bemerkenswerth die eigenthümlichen Ultraglieder, z. B. die ganz abseits stehende Gruppe der trotz grosser Basicität fast thonerdefreien und alkalifreien, aber enorm magnesiareichen Eruptivmassen, und ein anderes, vielleicht noch auffälliger aus dem allgemeinen normalen Rahmen herausfallendes Glied mit kaum 20 pro cent. Kieselsäure, alles andere fast nur Thonerde, dennoch aber ein ächtes Durchbruchsgestein.

Die neuere Zeit hat, auch zu dem Zweck, die Verwandtschaften hervortreten zu lassen, viele Bestrebungen hervorgebracht, formel-

ähnliche einfache Ausdrücke für die chemische Gesteinszusammensetzung zu gewinnen, sowie graphische Methoden zu ersinnen, wodurch das Verhältniss der einzelnen Stoffe, welche meist als aus den Gewichtsprocenten berechnete Molecularproportionen erscheinen, zur Darstellung gelangt, und der Ort angegeben wird, den eine Analyse inmitten einer Schaar von anderen einnimmt. Loewinson-Lessing, Pirsson, Michel-Lévy, Mügge, Brögger, Becke, Iddings, Osann haben auf diesem weiten Gebiete der chemisch-classificatorischen Formulirung, der Graphik und Topik verschiedene specielle Vorschläge gemacht.

Der zweite Hauptzweck der chemischen Gesteinsanalysen besteht darin, die an einem Material erfolgten substanziellen *Veränderungen* nachzuweisen, indem es mit demjenigen verglichen wird, an welchem dieselben nicht eingetreten sind. So haben die chemisch-analytischen Methoden jene grosse Summe von Kenntnissen aufgehäuft, die sich beziehen auf den gesetzmässigen Verlauf der einfachen Verwitterungen und der complicirteren Zersetzungen, welche unter dem Einfluss der allerwegen wirksamen Agentien und der dadurch zunächst beschafften carbonatischen und silicatischen Lösungen von Statten gehen. In das Verständniss von diesem stillen Spiel der chemischen Verwandtschaften und von dem gegenseitigen Austausch der Stoffe in den Felsen und Erdschichten zuerst Ordnung gebracht zu haben, ist das unvergängliche Verdienst des grossen Meisters Gustav Bischof.

Aber auch für die Einsicht in andere mehr locale Umwandlungen innerhalb der Gesteinswelt muss die Chemie helfend zur Seite stehen. Einmal da, wo in Folge des Durchbruchs von emporgedrängten Eruptivmassen die angrenzenden Gebirgsschichten oft auf weite Erstreckung hin in denjenigen veränderten Zustand versetzt worden sind, den man den *contactmetamorphischen* nennt. Soweit die Einwirkung des activen Eruptivgesteins auf die passive Umgebung in diesen hofähnlichen Umwandlungsgebieten erkannt werden kann, von der Grenze beider an, wo die Energie des Metamorphismus am intensivsten ist, bis dahin, wo die letzten äussersten Spuren in das unverändert gebliebene Nebengestein ausklingen, findet sich des betroffene Material, je nachdem es sich solchen Einflüssen gegenüber mehr oder weniger empfänglich verhält, in dieser oder jener Weise alterirt, indem an Hunderten über die ganze Erde verstreuten Orten auf

eine in den grossen Zügen übereinstimmende Art sein Mineralbestand und auch sein Gefüge zu einem anderen geworden ist. Auf chemischem Gebiete muss hier entschieden werden, ob es sich dabei um eine blosse moleculare Umlagerung der in dem Nebengestein vorhanden gewesenen Stoffe handelt, oder ob dasselbe auch eine wesentliche Veränderung seiner chemischen Zusammensetzung dadurch erlitten hat, dass die Eruptivmasse bei der Erstarrung etwa Stoffe aus sich ausschied und in dasselbe hinein abgab. Grosse Reihen von vergleichenden Analysen schienen, wenigstens für die Tiefengesteine, das Erstere zu bekräftigen, dass in der Regel diese contactmetamorphischen Ereignisse erfolgen ohne Zufuhr und Abfuhr von Substanzen, dass das active Gestein blos durch seine Eruption, durch die von ihm ausgeübten physikalischen Bedingungen des Drucks und der Temperatur wirkte, nicht auch durch die jeweilige Beschaffenheit seiner eigenen Masse. Französische Forscher sind freilich im Gegensatz dazu der Ansicht, dass auch bei den üblichen contactmetamorphischen Umwandlungen, z. B. von Thonschiefer in Hornfels, Fruchtschiefer, Garbenschiefer neu zugeführte Stoffe in dem Substrat eine Rolle spielen; dass Letzteres im Contact mit intrusiven Diabasen thatsächlich der Fall, wurde schon früh durch chemische Analysen erwiesen. Und wenn bei dem Durchbruch gewisser Granite durch ein Nebengestein sich das letztere, abgesehen von den sonst gewöhnlichen Alterationen, mit neugebildetem Turmalin, Topas, Zinnstein, Axinit, fluorhaltigem Glimmer in immer wiederkehrender geschlossener Gesellschaft ausgestattet zeigt, so ist es nicht zweifelhaft, dass die Entstehung dieser, vielfach an Spalten gebundener Mineralien in Verbindung gebracht werden muss mit einer die Granit-eruption begleitenden fumarolenähnlichen Aushauchung von fluor- und borhaltigen Dämpfen, also thatsächlich eine Aussendung fremder chemischer Stoffe in die Umgebung hinein stattgefunden hat.

Nun gibt es aber auch noch eine andere Art der Gesteinsmetamorphose als die durch Contact bedingte: die *gebirgsbildenden Druckkräfte* waren es, die in weiten Regionen das Material, auf welches sie wirkten, zusammengepresst, gestaucht, zermalmt haben, wobei es dann in der Regel zur Erwerbung eines anderen, namentlich schieferigen Gefüges und daneben auch zur Herausbildung eines abweichenden Mineralbestandes gekommen ist. Dabei erhebt sich

aber die wichtige Frage, wie es mit der chemischen Beschaffenheit solcher Druckproducte bestellt ist. Auf ein unzulängliches Material gestützt und im Banne von tendentiös erwünschten Vorstellungen hat man den Satz ausgesprochen, dass auch mit den weitestgehenden Umgestaltungen in Structur und Mineralführung eine chemische Veränderung von nennenswerthem Betrage *nicht* verbunden sei. Es ist das Verdienst von Reinisch, durch eine umfangreiche Analysenreihe dies als Irrthum aufgedeckt und für die druckmetamorphisch umgebildeten Orthoklasgesteine, für gepresste Diabase gezeigt zu haben, dass sie in gesetzmässiger Weise sogar einer recht erheblichen chemischen Veränderung unterlegen sind. Für die einzelnen Stoffe können bei normalem und gepresstem Gestein, welches den Gewässern Unmengen neuer Angriffspunkte bietet, die Differenzen so bedeutend werden, dass von einer unversehrten Erhaltung des chemischen Bestandes keine Rede mehr ist und dass damit das früher versuchte zurückschliessen aus der Analyse des Druckproducts auf das ursprüngliche Gestein—bei dem ganz verwischten chemischen Bilde des letzteren—einfach unmöglich wird.

Diese Beispiele zeigen, welch ein unentbehrliches Hülfsmittel die chemische Analyse für petrographische Probleme darstellt. Aber die Fülle des Dankes liegt doch nicht ganz allein auf der einen Seite, es lassen sich vielmehr auch gewisse Beziehungen anführen, wo umgekehrt die Chemie zu einiger Erkenntlichkeit Veranlassung hätte, indem sie durch die Petrographie nicht ganz gleichgültige Anregung zur Verschärfung oder Erweiterung ihrer eigenen Methoden erhalten hat.

Vor die Aufgabe gestellt, auch die nur ganz spurenhaft in den irdischen Gesteinen vorhandenen Elemente nachzuweisen, mussten die Chemiker darauf Bedacht nehmen, jene Reactionen ausfindig zu machen, wodurch diese Elemente am besten in ihrer Gegenwart erkannt, am schärfsten von einander getrennt und am sichersten quantitativ bestimmt werden können.

Die auf Begehr der Petrographie zu ihren Gunsten unternommenen Arbeiten z. B. von Hillebrand sind so der ganzen analytischen Chemie zu Gute gekommen. In Diensten der Petrographie fand Gooch die neuen Trennungsmethoden für Titan, Lithium, Bor und seinem erfinderischen Geschick verdanken die Chemiker den Gebrauch des

perforirten Platinfiltrirtiegels und des gekrämpten Platintiegels zur Wasserbestimmung. Der Mineralreichthum der Stassfurter Salzlager hat van't Hoff Anregung geboten zu seinen Jahrelangen wichtigen Untersuchungen über Gleichgewichtsverhältnisse, Löslichkeitscurven und Bildungsbedingungen von Hydraten, Doppelsalzen und Producten des doppelten Umtausches.

Neben der üblichen Makrochemie ist letzthin auch eine *Mikrochemie* erwachsen und ausgebaut worden. Hier unternimmt es das mikroskopisch bewaffnete Auge, die an dem zu prüfenden Object erfolgenden Veränderungen und die Natur der neu hervorgerufenen Producte zu erkennen. Haben die Reagentien auf ein winzig kleines Partikelchen oder ein Lösungströpfchen gewirkt, so kommt es vor allem darauf an, beim Verdunsten zwar nur mikroskopische, aber so charakteristisch krystallisirte und optisch wohl gekennzeichnete Producte der Reaction zu erhalten, dass sie zur zweifellosen Erkennung des dieselben bedingenden, in der Probe enthaltenen Elements verwerthet werden können, Wenn diese specifisch mikrochemischen Methoden, für zahlreiche Elemente äusserst befriedigend ersonnen und sehr häufig angewandt, jetzt der qualitativen Analyse zu Gebote stehen, so möge das Historische nicht vergessen werden, dass sie zuerst als etwas Neues lediglich um *petrographischer* Zwecke willen in die Wege geleitet wurden. Boricky war es, der 1877 bei seinen Gesteinsuntersuchungen auf die Idee kam, die Mineralpartikel mit Kieselfluorwasserstoff zu behandeln, um Fluorsiliciumsalze der Alkalien, der alkalischen Erden u. s. w. zu erhalten, die durch ihre unterscheidbaren Formen das in sie eingetretene neue Element verrathen.

Immer weiter um sich greift die Überzeugung, dass eine grosse Anzahl petrogenetischer Probleme ihr Verständniss finden wird auf dem Boden derjenigen Wissenschaft welche, obschon sie dem Namen nach zwischen zwei anderen steht, doch in letzterer Zeit mit ihren hochbedeutenden Errungenschaften eine förmliche Selbständigkeit beanspruchen darf, der *physikalischen Chemie.* Dass ihre Grundzätze, Gesetze und Arbeitsmethoden für petrographische Gebiete fruchtbar gemacht werden können, zum Theil schon verwerthet worden sind, mögen folgende skizzenhafte Andeutungen darthun.

Es ist eigenthümlich, dass ein Begriff, der als ein anscheinend neuer, durch seine Aufstellung grosses Interesse erweckte, der der

festen Lösungen, in der Petrographie schon lange Zeit vorher als eine selbstverständliche Thatsache gegolten hat. Wir haben von jeher gewusst, dass, indem das Lavamagma eine schmelzflüssige Lösung mit wechselndem Verhältniss der Mischungstheile ist, auch sein chemisch identisches, homogenes, festes amorphes Erstarrungsproduct, welches entsteht, wenn die moleculare Beweglichkeit aufhört, bevor krystallinische Ausscheidung beginnt, dass das natürliche Glas nichts anderes sein kann, als eine unterkühlte festgewordene Lösung.

Bei den natürlichen Silicatschmelzflüssen wird nicht mehr ein Gegensatz von gelösten Körpern und einem Lösungsmittel von bestimmter stöchiometrischer Zusammensetzung angenommen, es sind gegenseitige wahrscheinlich dissociirte Lösungen; die Speculationen über die Natur der auch ihrer Herkunft nach stets ganz problematisch gewesenen Lösungsmittel sind dadurch belanglos geworden.

Die Gesetze, welche die Krystallisation aus wässerigen Lösungen beherrschen, müssen, wie schon Bunsen hervorhob, auch gültig sein für schmelzflüssige. Zweifellos steht auch die Consolidation von natürlichen Schmelzflüssen unter der Herrschaft der von Gibbs für Salzlösungen aufgestellten Phasenregel; aber in Folge der Complicationen, welche durch die Gegenwart so vieler im Magma gelöst vorhandener Verbindungen bedingt werden, dürfte es schwerlich gelingen, auf diesem Gebiete ihre Wirkung auf die Ausscheidungsfolge zu specialisiren.

Als ein altes Hauptproblem gilt die *Reihenfolge*, in welcher die einzelnen Mineralgemengtheile eines gleichmässig körnigen Eruptivgesteins festgeworden sind, oder, genauer ausgedrückt, in welcher sie zu krystallisiren *angefangen* haben. Dass es keineswegs, wie Rosenbusch glaubte, die zunehmende Acidität ist, sondern nach dem Hinweis von Lagorio weit mehr die Natur der Basen, wodurch diese Succession in normalen Fällen geregelt wird, dürfte nicht mehr auf Widerspruch stossen. Diejenigen Stoffe, welche am leichtesten sättigen, werden zuerst zum Aufbau der Ausscheidungen verbraucht, die am schwersten sättigenden zuletzt Und experimentell ist nachgewiesen, dass die abnehmende Reihenfolge in der Sättigungsfähigkeit für schmelzende Silicatlösungen lautet: Eisenoxyde, Magnesia, Kalk, Natron, Kali und Thonerde, welche erst relativ spät in das

Molecül der verschiedenen Gemengtheile eintritt, dann Kieselsäure selbst. Doch liegen hunderte von wohlstudirten Beispielen vor, wo die darnach construirte Reihenfolge: Eisenerze, Olivin und rhombische Pyroxene, monokline Pyroxene, Amphibol und Biotit, Anorthit, Kalknatronfeldspathe, Nephelin, Albit und Aegirin, Orthoklas, Quarz nicht eingehalten wird, sei es, dass diese Reihe an gewissen Stellen eine *Umkehrung* erfährt, oder dass Mineralien, welche erst nach einander hätten krystallisiren sollen, *gleichzeitig* ausgeschieden vorliegen.

Blos zweierlei scheint ganz festzustehen: erstlich, dass in den kieselsäurereichen Gesteinen solcher Art mit Gehalt an Quarz dieser in der Regel mit zu den letzten Verfestigungen gehört, und sodann, dass die Träger der nur äusserst spärlich oder spurenhaft in dem Magma vorhandenen Stoffe, der Phosphorsäure, Zirkonsäure, Titansäure u. s. w., also Apatit, Zirkon, Rutil, Titanit, Ilmenit, Perowskit zu allererst zu krystallisiren anhuben, wenn sie auch in einigen Fällen, gleichwie die Erze, eine nicht unbeträchtlich lange Ausscheidungsdauer besitzen. Es ist fraglich, ob die frühe Festwerdung dieser Accessorien, wie oft geglaubt wird, in der That auf ihrem geringen Mengenverhältniss beruht, denn weil die Lösung dann für dieselbe verdünnt erscheint, hätten sie wohl eigentlich gerade umgekerht erst ganz spät auskrystallisiren müssen. Da man auch nicht, in etwas drastischer Weise, dem Magma das Bestreben zuschreiben kann sich dieser Fremdkörper gewissermassen zunächst zu entledigen, so ist zur Deutung der Thatsache vielleicht eher anzunehmen, dass jene Mineralien in der silicatischen Lösung bei niedrigeren Temperaturen besonders schwer löslich sind.

Die Ursachen für jenes abwechslungsvolle Verhalten der Hauptmineralien in ihrer Krystallisationsfolge sind zum guten Theil noch recht unbekannt. Die Behandlung der Frage gestaltet sich aber dadurch besonders schwierig, dass man bei Experimenten und theoretischen Erwägungen nur mit zwei Substanzen in Lösung zu operiren pflegt, während ein Silicatgesteinsmagma in der Regel über vier Substanzen gleichzeitig gelöst enthält.

Es wurde hingewiesen auf die Thatsache, dass in gewissen Lösungen der *Temperaturspielraum* für das Herausfallen *einer* Verbindung, z. B. Leucit, ein engbegrenzter, für das Auskrystallisiren einer

anderen Verbindung, z. B. Augit, unter sonst gleichen Umständen ein viel weiter begrenzter sein kann, so dass sich aus dem gleichen Magma je nach der Temperatur der Augit bald vor, bald nach dem Leucit auszuscheiden vermag. Auch Meyerhoffer hat gezeigt, dass je nach dem labilen Gleichgewicht aus derselben Schmelze bald *a*, bald *b* zuerst krystallisiren kann.

Noch durch ein weiteres Moment kann die Reihenfolge der Ausscheidungen verändert werden, durch den *Druck*. Da nach der üblichen Auffassung die gesteinsbildenden Mineralien sich beim Erstarren aus ihrer Schmelze contrahiren so muss, wie Sorby und Bunsen nachwiesen, verstärkter Druck diese Contraction befördern, d. h. die Krystallisation beschleunigen. Die damit zusammenhängende Verschiebung des Erstarrungspunktes erfolgt aber dann bei verschiedenen Körpern ungleichmassig, so dass zwei Körper, die unter einfachem Atmosphärendruck verschiedenen Erstarrungspunkt haben, unter erhöhtem Druck, unter welchem die Schmelzpunkte näher zusammengerückt sind, gleichzeitig erstarren können, während unter noch stärkerem Druck der vorher rascher erstarrende zum langsamer erstarrenden werden kann, auf Grund dessen sich die Reihenfolge der Ausscheidungen ändert, z. B. zwischen dem leichter schmelzbaren Augit und dem schwerer schmelzbaren Orthoklas.

Nach Doelter könnte auch die *Krystallisationsgeschwindigkeit* in so fern von Belang sein, als der Vorsprung, welchen die schwerere Löslichkeit einer Substanz *a* für ihre frühere Ausscheidung hat, eingeholt oder überholt wird durch die raschere Krystallisationstendenz einer leichter löslichen Substanz *b*. Tritt dies nicht, wie es der Fall sein sollte, allenthalben ein, so liesse sich als Ursache dafür vielleicht die abweichende Viscosität der Magmen anführen, mit welcher sich die Krystallisationsgeschwindigkeit ändert; sollte die Viscosität, die Zunahme der inneren Reibung, der Auskrystallisation von *a* und *b* gleichmässig entgegenwirken, so würde jener Vorsprung nicht so leicht oder überhaupt nicht eingeholt werden.

Andere physikalisch-chemische Fragen auf diesem Gebiete sind die warhscheinlich zu verneinende, ob und wie weit die Reihenfolge der Ausscheidungen beeinflusst wird durch die *relativen Mengenverhältnisse* der Bestandtheile; über die noch wenig untersuchte Wir-

kung der sog. *Impf*-krystalle; sodann, ob in gewissen gleichmässig-fein und in bestimmtem Verhältniss gemengten Aggregaten zweier Mineralien, die sich an den Felsarten betheiligen, etwa das Product einer *eutektischen Mischung* im Sinne Guthrie's, analog den Kryohydraten, vorliegt. Weiterhin über die Rolle, welche die sog. *Mineralisatoren*, die "agents minéralisateurs" bei der Verfestigung des Magmas spielen, jene darin vorhandenen, zum Theil gasigen Stoffe, welche auf die Auskrystallisation rein katalytisch zu wirken scheinen, d. h. dieselbe befördern, ohne selbst dabei verwandelt zu werden und ohne in die bei ihrer Gegenwart sich bildenden Substanzen einzutreten. Besser sind wir, namentlich durch Iddings, darüber unterrichtet, durch welche Ursache die so häufigen magmatischen *Corrosionen* und Resorptionen, die Wiederauflösungen bereits ausgeschiedener Gemengtheile bedingt werden, wobei es sich um Verschiebung des Gleichgewichtszustandes zwischen der festen und flüssigen Phase handelt.

Ganz besonders wird aber auch die Mithülfe der physikalischen Chemie Noth thun bei der Erklärung der *Differenzirung der Magmen*, der weithin verbreiteten Erscheinung, dass umfangreiche Eruptivmassen, auch mächtige Gänge, sich gespalten haben in ein saureres, vorwiegend alkalisches, auch thonerdereicheres und in ein basischeres, an Eisen- und Magnesiasilicaten reicheres, an Thonerde und Alkalien armes Theilmagma, wobei das erstere fast immer im Centrum, das letztere als basische Randfacies an der Peripherie lagert. Die Entstehung dieser Theilmagmen muss während des Flüssigkeitszustandes durch Diffusionen in entgegengesetzter Richtung vor sich gegangen sein und so handelt es sich insbesondere um zwei Fragen: 1., welche Kräfte überhaupt die Separation in die abweichend beschaffenen polar entgegengesetzten Theilmagmen, das Zusammengehen der zweiwerthigen Metalle mit einander und mit wenig Silicium, das der einwerthigen mit mehr Aluminium und mehr Silicium veranlasst haben, und 2., weshalb das acidere Theilmagma nun gerade die centrale, das basischere die peripherische Stelle eingenommen hat.

Mehrere Einwendungen lassen sich dagegen erheben, hier das von Soret aufgestellte, von van't Hoff ausgebaute Princip zur unmittelbaren Anwendung zu bringen, dass der oder die Bestandtheile, mit denen eine Solution nahezu gesättigt ist, sich an den kälteren Stellen

anzuhäufen streben; der Satz ist z. B. nur für die Vertheilung *eines* gelösten Stoffs in einem Lösungsmittel nachgewiesen. Guy und Chaperon's Satz, dass die Schwere mitwirkt die Homogeneität einer Solution aufzuheben, kann hier keine Gültigkeit beanspruchen, denn dann müsste das schwerere basischere Theilmagma in einem unteren, das leichtere acidere in einem oberen Niveau erscheinen und der Gegensatz zwischen Centrum und Peripherie würde dadurch nicht erklärt. Wer aber in schwer verständlicher Weise die Erscheinung der randlichen Basicität auf eine Einschmelzung angrenzenden Nebengesteins zurückführen will, setzt sich mit einer Unmenge von Thatsachen in Widerspruch und verneint ausserdem überhaupt eine stattgefundene Differenzirung.

Einen wesentlichen Schritt zur Förderung der Erkenntniss hat Brögger gethan, welcher in speciellen Fällen nachwies, dass es wohl nicht die einzelnen Stoffe, sondern bestimmte stöchiometrische Verbindungen gewesen sind, welche eine entgegengesetzte Diffusionsrichtung verfolgt haben, indem sich die kieselsäurearmen Eisen-Magnesia-Kalksilicate in der einen, die kieselsäurereichen Alkali-Thonerdesilicate in der anderen Richtung bewegten und dass ausserdem diese Verbindungen als solche den Mineralien der Eruptivgesteine entsprechen, in denen, wie bekannt, ja auch Alkalien, Aluminium nebst Calcium einerseits, Magnesium, Eisen nebst Calcium andererseits zusammenzugehen pflegen. So seien es die am schwersten löslichen Verbindungen, welche nach der Abkühlungsfläche hin diffundiren und in so fern hänge die Differenzirung zusammen mit den die Krystallisationstendenz beherrschenden Gesetzen. Ähnlichen Vorstellungen scheint sich Harker hingegeben zu haben. Hierin liegt gewiss eine wichtige Erläuterung, welche aber nur Thatsachen erkennt, keine eigentliche Erklärung gibt, und immerhin bleibt es eine Frage, worin denn nun jene treibende Kraft besteht, vermöge deren der melanokrate Pol gerade eine peripherische, der leukokrate eine centrale Position einnimmt. Uber die Unterschiede in den Diffusionsconstanten der betreffenden Verbindungen ist nichts bekannt.

Um ähnliche Gegensätze, wie sie zwischen Centrum und Rand in einem und demselben Massiv bestehen, handelt es sich da, wo in einer Gegend viele sog. *complementäre Gänge* aufsetzen, acidere neben

basischeren, welche dann aufgefasst werden, als spaltenerfüllende Producte einer in übereinstimmender Weise zur Geltung gekommenen Differenzirung eines plutonischen Magmas.

Eine hoch wichtige Frage ist es, ob das gluthflüssige Eruptivmagma beim Ubergang in den starren krystallinischer Zustand eine *Verminderung* oder eine *Vermehrung* seines Volumens erfährt. Gustav Bischof, Mallet und David Forbes haben sich auf Grund von experimentellen Untersuchungen bei basischen Flüssen für das Eintreten einer Zusammenziehung um *ca.*1/10 der Masse ausgesprochen, womit auch die Entstehung von Contractionsrissen in der verfestigten Lava übereinstimmt. Die vielcitirten Versuche von Barus wurden in der Weise ausgeführt, dass das feste Gestein zurückgeschmolzen und dabei im Einklang mit dem Vorhergehenden nun eine Volumvermehrung der Schmelze constatirt wurde.

Die Frage hat aber dadurch wieder die Aufmerksamkeit in hohem Grade auf sich gezogen, weil sie bei der neuen Vulkantheorie von Stübel eine wesentliche Rolle spielt. Stübel läugnet, dass der Druck der sich contrahirenden Erdkruste auf den eigentlichen gluthigen Erdkern die vulkanischen Erscheinungen bewirke; er hält dafür dass es die in der langsam erstarrenden sog. Panzerdecke der Erde restlich erhalten gebliebenen und nestähnlich abgefangenen relativ kleinen Reservoirs von gluthflüssigem Magma sind, welche dadurch zur Eruption auf einem Ausbruchscanal gelangen, dass bei dem Erstarrungsprocess eine Volumvergrösserung eintritt. Da er nun aber, angesichts der bisherigen Ergebnisse, es doch selbst als wohlbegründet anerkennen muss, dass wenigstens der Schlusseffect umgekehrt in einer Contraction besteht, so glaubt er es als höchst wahrscheinlich annehmen zu dürfen, dass innerhalb des Erkaltungsprocesses eine vorübergehende Phase der Schwellung, der Volumvermehrung, sich einstellt; experimentell ist aber darüber gar nichts bekannt.

Ein weiteres physikalisch-chemisches Princip, welches petrographische Vorgänge innerhalb der Sedimentgesteine erklärt, ist das Bestreben, die vorhandene *Oberfläche* für eine Summe neben einander gelagerter gleichartiger Individuen möglichst zu *verkleinern.* Nur wenn die Berührungsfläche zwischen einem Krystall und seiner gestättigten Lösung ein Minimum ist, scheint das Gleichgewicht

zwischen beiden erreicht zu sein. Befeuchtet man das Pulver löslicher Salze und lässt es längere Zeit stehen, so nimmt die Masse eine deutlich krystallinische Zusammensetzung aus grösseren Individuen an, ein Theil der kleinen Partikelchen wächst in seinen Dimensionen auf Kosten der anderen, welche dabei als solche aufgezehrt werden. Auf ähnliche Weise wird auch durch Rekrystallisation nach solchem Gesetz und mit solcher Wirkung die Structurbeschaffenheit derjenigen grosskörnigen Marmore gedeutet, für welche es wahrscheinlich ist, dass sie früher ganz dichte Kalksteine dargestellt haben, indem unter der Gegenwart kohlensäurehaltigen Wassers die kleinen Körnchen das Bestreben haben, durch gegenseitige Assimilation und durch Umlagerung ihrer Molecüle zu gleichartiger Orientirung in einander aufzugehen und sich zu grösseren Individuen auszuwachsen. Ferner wird so das bisweilen ziemlich grobe Korn der älteren Salzbildungen verständlich, während die Absätze der Jetztzeit aus den Salzseen fast dicht ausfallen, ebenso das Wachsthum des Gletscherkorns vom Firn abwärts bis zum unteren Ende des Eistroms.

Da die Petrographie einen Theil der *Geologie* bildet, so ist die enge Verbindung selbstverständlich; beide ergänzen sich gegenseitig und eine Geologie ohne Petrographie gibt es nicht, wie auch keine Petrographie, welche die auf anderen Gebieten der Geologie gemachten Enfahrungen vernachlässigen könnte. Davon hier specieller zu reden dürfte jedoch in ähnlicher Weise nicht erforderlich sein, wie wenn man das Verhältniss von Palaeontologie und Geologie auseinandersetzen wollte.

So steht die moderne Petrographie heute da inmitten eines reichen Kranzes angrenzender Wissenschaften, von hüben und drüben fliesst Anregung, Erkenntniss und Belehrung im glüchlichen Wechsel zusammen. Wenn aber auch von unserer Wissenschaft kaum das stolze Anerbieten an die Nachbarn ausgehen darf: "do ut des, ich gebe, damit Du gibst," so lässt sie doch nicht vergeblich und ohne ihrerseits zu viel zu versprechen, die bescheidenere Bitte erklingen: "da ut dem, gib Du mir, dann gebe ich auch etwas."

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AN OCCURRENCE OF GREENSTONE SCHISTS IN THE SAN JUAN MOUNTAINS, COLORADO.[1]

In the course of a recent examination of the Needle Mountains quadrangle by the United States Geological Survey, a series of metamorphic rocks was encountered that differs in many respects from those occurring near by in the Animas Canyon, which have been considered to be of Archean age.

The region is near the southwestern limits of the San Juan Mountains of southern Colorado, which are made up largely of Tertiary volcanic rocks. In that portion which is known locally as the Needle Mountains, and which lies in parts of San Juan and La Plata counties, the younger lava flows and breccias are absent, and ancient crystalline or metamorphic rocks have been exposed by the dissection of a dome-like uplift, in which all of the sedimentary formations, as late at least as the last of the conformable Cretaceous beds, have been involved. These rocks, which are all of pre-Cambrian age, are granites, schists, and quartzites; the ones to be described, which may be referred to conveniently as greenstones, occur at the southern side of the uplift.

During a hurried visit to the region in 1901, one of the members of the party, who was familiar with the Marquette and Menominee greenstones, called attention to the similarity of these rocks to those of the Lake Superior region. In the next field season a more detailed study was made of the complex, and in the laboratory specimens of the Needle Mountains rocks were compared with those collected by the late G. H. Williams in the Marquette and Menominee localities, as well as with specimens described by Cross from near Salida, Colorado, in the Arkansas Valley.

Occurrence of the greenstones.—The greenstones are found for a little over seven miles in a north-and-south direction on both sides of Vallecito Creek, midway between its head and the point where it joins Pine River. From east to west the area occupied by the greenstones is not more than two and a half miles wide at most. To the

[1] Published by permission of the Director of the U. S. Geological Survey.

north and east they are sharply bounded by fault contacts with sedimentary rocks of pre-Cambrian age, or have been intricately infolded with them; another fault separates the greenstones on the west from a large mass of granite, while to the southward they disappear beneath the Paleozoic sedimentaries.

Many of the exposures are of well-banded schistose rocks, and it was only natural that they were at first assumed to be a part of the great Archean complex of schists and gneisses known to occur near by in the Animas Canyon. On closer study, however, it soon became evident that there were marked differences between the two series of rocks. The Irving formation, as the greenstone complex has been named, from Irving Peak, was found to consist, not only of the schists first observed, but also of massive basic rocks sometimes possessing a porphyritic structure, others partly mashed or brecciated, and a few distinctly granular, while no well-defined system of bedding or stratification could be made out. All of the rocks are of a dull greenish color and appear to have undergone extensive alteration. At two places massive quartzite was found, and at a number of localities extremely siliceous schists occur, some of which have undoubtedly been derived from quartzites through dynamic metamorphism, while others must have been originally granites or closely allied rocks. A single band of siliceous magnetite some fifteen feet in thickness was also observed near the northern end of the series.

Most of the exposures are a dull leaden-gray or green, in sharp contrast to the lighter-colored granites and quartzites to the north and west, and their somber tones add to the gloomy aspect of the valley sides which have, in many places, been swept by destructive forest fires. The dull monotony is occasionally relieved by dikes of bright red granite porphyry or pegmatite near the contact with the granite mass to the westward. The only marked variations in the Irving formation itself are the comparatively rare occurrences of a very light gray gneiss or mashed quartzite.

Description of the rocks.—The majority of the rocks found in the Vallecito section display considerable textural variety, but appear to be o nearly the same mineralogical composition. Hornblende, chlorite, epidote, and rarely biotite can be recognized megascopically in nearly all, and usually these dark minerals appear to be in excess

of the lighter silicates; what feldspar there is has evidently been much altered. The most significant features of the rocks in different parts of the complex are the variations in texture and structure which are conspicuous in the field and still more so when the rocks are examined microscopically. As will be shown later, these are due partly to original textural differences in the rocks themselves, and in part to their dynamic metamorphism that has produced, in some instances, finely laminated schists in which all traces of original structure have been obliterated.

In the field and laboratory two distinct kinds of massive rocks have been recognized, and transitions between them and the schists may be followed in many cases. Rocks of the first kind are granular and of a medium texture. The second consist of porphyries with phenocrysts of eldspar and hornblende in a very fine-grained groundmass, or are extremely dense, without phenocrysts and resemble the finer-grained diabases. A number of rocks of intermediate textures have been found, but the two groups may be considered as fairly well defined for purposes of description.

Massive granular greenstone or metagabbro.—Occurrences of strictly granular rocks are not numerous. The best examples have been found in a restricted area which includes Irving Peak and its southwestern flanks near the northern limits of the complex. The texture of these rocks is practically the same as that of many medium-grained gabbros, the only differences being that laths of plagioclase cannot be made out, and that the dark amphibole, although it appears to be in the form of blades or lath-shaped crystals, is, in reality, fibrous. The average rock is moderately coarse, even-grained, but specimens from the summit of Irving Peak show a tendency toward the formation of fine-grained segregations richer in hornblende. On fresh surfaces the color is a dark bluish- to greenish-gray.

A microscopical examination shows at once that the rocks are more or less metamorphosed. The chief constituents are hornblende, plagioclase, and generally a very little biotite and magnetite. The plagioclase is seldom fresh enough to permit of an exact determination of its character, but the large extinction angles indicate labradorite. The feldspar and hornblende are present in about equal quantities in large irregular patches rather than grains. The

feldspars seem, in many cases, to have possessed crystal boundaries and were often typically lath-shaped. At present, even in the freshest specimens, they are much altered to calcite, muscovite, zoisite, and epidote, and individual grains have been bent and broken, but are not crushed. Hornblende, which is, as a rule, quite fresh, is of the pleochroic fibrous variety, uralite, and there can be little doubt as to its secondary origin; it sometimes appears almost massive, but the borders are extremely ragged, and minute blades and needles are scattered throughout the rock and often penetrate the feldspar areas. Biotite is unimportant and occurs more in the nature of an accessory.

Although from their mineralogical composition these rocks might be classed as diorites, and although no trace of pyroxene has been found, still from their resemblance to rocks of other regions, especially in the Menominee district, where all the stages in the change from gabbro to hornblende rock may be observed, they are to be regarded as gabbros in a rather advanced state of alteration.

Porphyritic and fine-grained greenstones.—The mineralogical composition of the porphyries and greenstones of finer grain is essentially the same as that of the granular rocks, the hornblende being possibly a little more prominent. Alteration, however, is generally more advanced, but strangely enough the original structures are often well preserved, even where the feldspars have been completely saussuritized or changed to other secondary minerals, and the dark silicates have been altered to chlorite. The structure which seems to prevail in all of the finer-grained rocks is the ophitic, so typical of diabase, in which laths of plagioclase lie, as it were in a groundmass of pyroxene and magnetite. In the case of the greenstones the outlines of the feldspar laths are distinct, and the crystals often appear to radiate from a central point. What should correspond to pyroxene is, in the greenstones, either a mesh of uralite needles or chlorite, together with smaller grains of undeterminable feldspar and occasionally quartz. Here, there can be no doubt that the rocks were derived from diabase or diabase porphyry by the well-recognized change of pyroxene to hornblende and the alteration of labradorite to saussurite, accompanied by the development of epidote and calcite.

Between these altered massive rocks and the finely laminated schists, a series of rocks may be found which illustrates the various stages of dynamic metamorphism, and satisfactorily proves the close relation of the schists and massive greenstones. The bending and fracturing of the feldspars is followed by more complete crushing, and the hornblende is broken up and redistributed in small parallel blades through the rock. In extreme cases recrystallization has probably taken place, and the minerals in such rocks are, as a rule, much fresher than in many of the less mashed varieties.

Greenstone schist.—The more or less completely schistose rocks which make up the major part of the Irving series differ but little from many of the schists of the Archean. They are fine-grained and well laminated and of a dark greenish-gray color. The microscope shows them to be made up of pleochroic green hornblende in excess of finely granulated feldspar, and usually biotite, a little quartz, and magnetite. The parallel arrangement of the minerals, especially of the blades of hornblende and biotite, is very striking. Feldspar sometimes occurs merely as interstitial grains between the dark silicates, but usually it is present as a fine mosaic in long-drawn-out lenses or bands. In some cases chlorite has completely replaced hornblende, and muscovite has been developed at the expense of part of the feldspar.

Siliceous schists.—At a number of localities within the greenstone area schists and gneisses of a much less basic character have been found. They are light gray or nearly white in color, the dark silicate is biotite, and the feldspar, when recognizable, orthoclase and microcline, with only small quantities of plagioclase. Quartz is abundant, and the microscope shows that magnetite, muscovite, and rarely augite or hornblende, may occur as accessories. In all cases the mashing has been sufficient to destroy original textures and develop an excellent schistosity or lamination. Except in one or two doubtful cases, to be noted later, these rocks appear to have been formerly intruded into the greenstones as granites, and subsequently to have shared with the older rocks in the mashing and deformation of the region.

The exceptions just mentioned are some unusually siliceous rocks whose relations to the greenstones are not altogether clear.

Like the others, they are very completely mashed and contain both feldspar and biotite, but the amount of quartz is largely in excess of that of all the other minerals. The occurrence of massive quartzite with the Irving greenstones has already been referred to, and it seems more than likely that these siliceous schists are quartzites that lay within zones of great mashing and suffered with the rest of the rocks.

Structure.—It has not been possible to find any evidence of original bedding in the Irving greenstones, although frequently, on account of their schistosity, the rocks appear to be stratified. This banding, though predominant, is not a constant feature, and transitions may be observed from schists to unmashed rocks which have the composition and textural characteristics of intrusives. In addition to the schistosity, which is generally vertical and with a northwest-southeast strike, the massive greenstones, more especially near their contact with the Algonkian conglomerates and quartzites, have been fractured and brecciated. These conditions were probably brought about at the time that the shearing and complicated infolding took place between the Algonkian sediments and the Irving greenstones. In a very few cases it has been possible to recognize dikes of compact greenstone cutting either coarser rocks of the same sort or siliceous schists.

The petrographical examination of the rocks failed to show that they had occurred as surface flows, all of the characteristics being those of intrusive rocks. The only possible exceptions are certain rocks near the eastern border of the greenstone area. They are considerably altered and have been mashed, and their field appearance suggested that they were flow-breccias or tuffs, with fragments or drawn-out lenses of greenish porphyry lying in a dense cementing material of a darker color. Unfortunately, decomposition has proceeded too far for a microscopical examination to be of value; secondary minerals are about the only ones that can be made out, but the texture suggests crushing or mashing. The occurrence of these rocks seems to be restricted to the region immediately adjoining the contact with the Algonkian conglomerates, where, as has been said, complicated infolding and fracturing have taken place, and it is more reasonable to suppose that these rocks are friction breccias, subsequently mashed, than that they are of pyroclastic origin.

Age of the greenstones.—The oldest rocks in contact with the Irving greenstones are the conglomerates and quartzites of the Algonkian to the north and east. The actual relations of the two formations have been obscured by faulting or infolding, but the greater age of the Irving is shown by the quantities of schistose and massive greenstone pebbles in the lower portions of the Algonkian conglomerate. The character of these pebbles also supplies information in regard to the age of the mashing of the Irving greenstones, the greater part of which evidently took place before the deposition of the conglomerate. Later movements occurred after Algonkian time and resulted in the further fracturing and mashing of the greenstones, as well as the lower portions of the conglomerate.

As to the lower age limits, little can be said with certainty, except that the rocks have been less affected by dynamic metamorphism than any that are known to occur in the neighboring Archean areas. They have been regarded as of early Algonkian age, separated from the younger Algonkian sediments by an erosion interval of unknown extent. That the Irving, as now exposed, represents but a small part of a much greater series of rocks which formerly existed seems certain. Evidence of this is to be found in the great thickness of Algonkian conglomerates, for, although greenstone pebbles are conspicuous in many places, quartzite débris is more abundant, and lenses or beds of magnetite or jasper bowlders are often seen high up in the section, all of which indicates the destruction of an earlier terrane, the only traces of which that may now be recognized being the comparatively rare beds of quartzite and magnetite associated with the Irving greenstones. These same remnants are believed to be inclusions in the diabase and gabbro which intruded sediments that have since been worn down to supply the materials for the younger series of quartzites.

Comparison with rocks of other localities.—The collection of rocks from the Menominee and Marquette regions made by the late G. H. Williams, and described by him in a bulletin of the United States Geological Survey,[1] has been examined in connection with the present study, and a certain similarity between the two series of rocks

[1] G. H. Williams, "The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan," *Bulletin No. 62* (1890), U. S. Geological Survey.

has been found in a number of cases. Professor Williams states that "there is considerable evidence to show that the greenstones, both of the Menominee and Marquette regions, solidified at the surface, under subaërial or subaqueous conditions." There are, however, a number of instances where the rocks are clearly intrusive, and it is these that the Irving greenstones most closely resemble. The character of the metamorphism appears to have been the same in both regions, and the rocks from which the greenstones were derived were undoubtedly very similar. The most important difference is that tuffs and surface flows have been recognized in the Lake Superior complex, while no rocks of this nature have been seen in the Irving. Flows or fragmental deposits of igneous origin may, of course, have been originally present, but all traces have been destroyed.

The Irving greenstones and those occurring near Salida in the Arkansas Valley, some 125 miles to the northeast, possess a number of common characteristics; in fact, the description by Mr. Cross[1] of the hornblendic members of the Salida rocks might be applied directly to those in the Needle Mountains. In both localities granular hornblendic rocks occur and also denser rocks in which the microscope reveals an ophitic structure. The only rocks found in the Salida section which differ greatly from those of the Irving are ones which are in some instances sufficiently well preserved to indicate a structure and composition like that of rhyolite, and which in extreme cases of metamorphism suggest finely mashed micaceous quartzites. There are not sufficient data in regard to the field occurrence of these rocks to make it possible to say whether they were originally surface flows or intrusives, but in regard to the series as a whole, Cross is inclined to believe that they represent "a great series of surface lavas erupted in Algonkian time."

In a recent monograph of the United States Geological Survey, Bayley[2] has redescribed the greenstones of the Menominee region under the name of "Quinnesec schists" and has referred them to

[1] On a Series of Peculiar Schists Near Salida, Colorado. *Proceedings of the Colorado Scientific Society*, Vol. IV (1893), pp. 286–93.

[2] W. S. Bayley, "The Menominee Iron-Bearing District of Michigan," *Monograph 46* (1904), U. S. Geological Survey.

the Archean. The greenstones of the San Juan Mountains are most clearly associated with Algonkian rocks, and, aside from their lithological similarity, there seem to be no good reasons for attempting to correlate such distant occurrences as the Quinnesec and Irving schists.

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AN OCCURRENCE OF TRACHYTE ON THE ISLAND OF HAWAII.[1]

THE Hawaiian Islands are commonly described as consisting almost wholly of basaltic lavas, though in truth there is a known wide range in the rocks thus broadly characterized. These lavas have issued as flows from many centers, building up great volcanic mountains. The eruptions have continued for a long time with gradually shifting scene of action, and agencies of degradation have reduced some ancient basaltic mountains to mere reefs, while other volcanic piles are now like deeply dissected models, showing their constitution to the very core. With all this opportunity to examine the products of Hawaiian volcanoes of various epochs and at many centers, no one has, to the writer's knowledge, found and described any other than basaltic or related lavas as existing in the entire group. However, during the summer of 1902, while the writer was engaged in a reconnaissance of the Hawaiian Islands for the Geological Survey, he was fortunate enough to discover an occurrence of trachyte which, from several standpoints, seems to merit description.

The locality at which this unique rock was found is on the island of Hawaii, at the northern base of Mount Hualalai, one of the great basaltic volcanoes of the island, the last eruption of which took place in 1801, from a low-lying point near that at which the trachyte occurs. The accompanying map shows the geographic position of the trachyte locality.

Mount Hualalai is a basaltic cone of the Mauna Kea type, rising 8,000 feet above the sea, consisting mainly of lava flows, but dotted with numerous small cinder cones and punctured by perhaps as many remarkable "pit craters." The cinder cones are most numerous near the summit of the mountain, and, so far as the writer is aware, the products of all these recent and local outbursts are basaltic in character. The later lavas on the northern slope are olivine-rich plagioclase basalts.

[1] Published with the permission of the Director of the United States Geological Survey.

Near the northern base of Mount Hualalai is a tuff cone, notably larger than those on the upper slopes of the mountain, and forming a very striking feature of the landscape as seen from the north. This cone, called Puu Waawaa, seems at first, like many others, an excres-

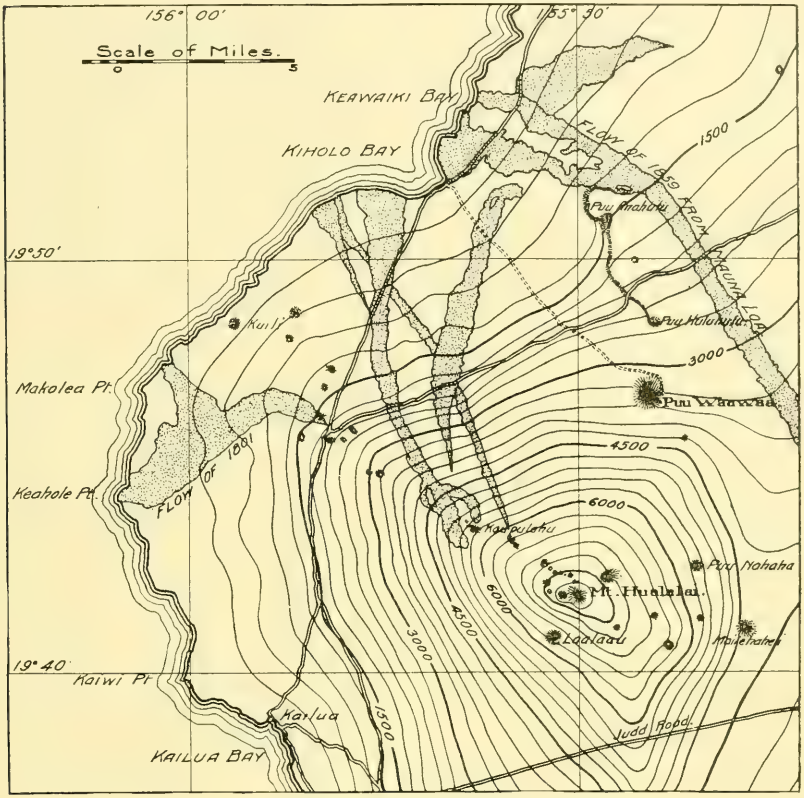

FIG. 1.—Map of a portion of the island of Hawaii.
(From map issued by Hawaiian Government Survey.)

cence on the surface of the larger volcano, but the material of which it is made is the trachytic lava to be described, and it is a matter for future observation to determine whether the situation relative to Mount Hualalai is not, as the writer suspects, quite a matter of chance. The base of Puu Waawaa is at about 3,300 feet above the sea and its summit several hundred feet higher. Adjacent to the cone of Puu Waawaa on the north, and extending west of north for

three miles, is a very clearly defined bench or terrace with abrupt western border and northern end. A small point on its surface gives the name Puu Anahulu. This bench is indicated on the map by the hachures marking its steep western slope.

On the south the terrace of Puu Anahulu merges with the low grade slopes of Mount Hualalai and on the east with the surface of still smaller angle down which lava flows have come from Mauna Loa, some thirty miles away. Some of the late flows from Mount Hualalai have spread over the terrace, and in places have fallen in a stony cascade down the steep western bank. Others from the same source have passed between the terrace and the cone of Puu Waawaa. Some from Mauna Loa have also poured over portions of the bench or passed around its northern end to the sea. Puu Waawaa has been encircled by lavas from Hualalai which have cut it off from the terrace.

The terrace bench of Puu Anahulu is made up, so far as observations go, of an agglomeratic aggregate of large and small fragments of the rock to be described. In general, this rock is much decomposed by kaolinization, only the larger fragments still consisting in part of dark gray material. The softer, light-colored rock has been used for road metal on the new government road from Waimea to Kona, which passes over this bench. Both the bleached and the darker rock exhibit a rude schistosity due to a parallel arrangement of minute feldspar tablets, like that common in phonolite and in some trachytes.

Puu Waawaa is scored by numerous radial ravines penetrating its slopes for fifty feet or more, and in all of them examined the typical structure of a tuff cone is revealed. The cone seems to be made up of tuffs of varying texture, well stratified, and dipping nearly with the slope of the cone. Most of the tuff is made up of ash or fine gravel, with angular fragments irregularly distributed through it, which rarely exceed a few inches in diameter.

The fragments consist of brown pumice, dark aphanitic, or black obsidian-like rocks, with some showing a mingling of the latter materials. The dark aphanitic fragments are not unlike some dense basalts of the island in appearance, yet resemble also the freshest rock from the bowlders of Puu Anahulu.

Thin sections of the obsidian show it to be a colorless glass containing streams of feldspar microlites in some parts and free from them in others. The dull aphanitic streaks and masses are largely crystalline, with more or less of fine magnetite dust and ferritic globulites, and a colorless glassy base of variable amount.

To ascertain the chemical character of this rock an analysis was made by Dr. Hillebrand of the black glassy portion, with the result given in column 1 of the subjoined table. It is clearly an almost anhydrous, trachytic obsidian of close relationship to many other known rocks, of which analyses are also given in the tables, a resemblance which will be discussed in a later paragraph.

There is every reason to suppose that the associated pumice is of the same character as the obsidian, since no other rocks were observed among the fragments of the tuff.[1]

Turning now to the rock occurring in fragments at Puu Anahulu, microscopical examination shows it to be a felsitic trachyte, holocrystalline in the specimens examined, of typical trachytic texture. The feldspar microlites forming the greater part of the rock are mainly very small, averaging but $0.02–0.05^{mm}$ in thickness, less than 1^{mm} in length, and, while some are prismatic, many are more or less tabular in shape, causing by their nearly parallel fluidal arrangement the characteristic semi-schistose texture of the rock, which has already been commented upon.

The feldspars are fresh, and among them may be recognized sanidine, anorthoclase, and probably albite. The sanidine forms somewhat larger microlites than the anorthoclase and albite, but a distinct porphyritic texture was not observed.

The feldspars make up more than four-fifths of the trachyte. The norm of the obsidian analyzed indicates a possible content in nephelite for the perfectly fresh rock, but a careful search for this mineral failed to reveal it in the sections of the somewhat altered Anahulu trachyte. The remainder of the rock consists of magnetite and apatite, in small amounts, and two or more undetermined minerals which occur for the most part in the angular interstitial spaces between

[1] The writer's observations at Puu Waawaa were necessarily quite limited and leave much to be desired. He did not have time to explore the cone thoroughly, but from the facts noted on the north and east slopes, it seems probable that Puu Waawaa is composed solely of tracyhte tuff.

ANALYSES OF HAWAIIAN TRACHYTES AND ALLIED ROCKS.

No.	1	2	3	4	5	6	7	8
SiO_2	62.19	62.11	64.28	62.70	60.50	57.52	60.39	63.09
Al_2O_3	17.43	w	15.97	16.40	16.86	18.46	22.57	18.44
Fe_2O_3	1.65	w22.97	2.91	3.34	1.67	2.23	0.42	2.90
FeO	2.64	w	3.18	2.35	2.54	2.44	2.26	1.36
MgO	0.40	......	0.03	0.79	1.11	1.08	0.13	0.16
CaO	0.86	0.85	0.85	0.95	2.95	2.12	0.32	1.00
Na_2O	8.28	6.89	7.28	7.13	6.46	7.58	8.44	7.25
K_2O	5.03	4.82	5.07	5.25	5.42	4.08	4.77	5.23
H_2O+	0.39	1.60	0.20	0.70	1.40	1.80	0.57	0.62
H_2O-	0.14		......	......	......	......	......	0.21
CO_2	0.02	trace	......	......	0.70	......	trace	......
TiO_2	0.37	......	0.50	0.92	0.75	0.92	......	0.45
ZrO_2	0.04	......	......	......	......	......	......	......
P_2O_5	0.14	......	0.08	......	0.21	0.21	......	......
SO_3	none	......	......	......	......	......	......	......
Cl	......	......	0.12	......	......	......	......	......
Cr_2O_3	trace	......	......	......	......	......	......	......
NiO	none	......	......	......	......	......	......	......
MnO	0.32	......	trace	......	0.20	......	0.08	......
BaO	0.03	......	none	......	......	......	......	......
SrO	none	......	trace	......	......	......	......	......
Li_2O	trace	......	trace	......	......	......	......	......
	99.93	......	100.33	100.53	100.77	99.64	99.95	100.77

No.	9	10	11	12	13	14	15	16
SiO_2	61.08	66.22	63.24	66.50	63.20	60.11	63.76	66.06
Al_2O_3	18.71	16.22	17.98	16.25	17.45	19.01	17.37	16.46
Fe_2O_3	1.91	1.98	2.67	2.04	3.60	4.63	0.10	2.25
FeO	0.63	0.16	0.85	0.19	......	0.37	1.11	1.10
MgO	0.08	0.77	0.63	0.18	0.75	0.23	0.93	0.19
CaO	1.58	1.32	0.93	0.85	1.40	0.66	1.72	0.79
Na_2O	8.68	6.49	6.27	7.52	6.90	6.53	6.69	6.81
K_2O	4.63	5.76	5.47	5.53	5.88	5.36	5.97	5.52
H_2O+	2.21	0.24	0.80	0.50	0.50	1.37	0.40	0.62
H_2O-	......	0.08	0.37	......	......	......	......	
CO_2	......	......	......	......	......	0.84	......	......
TiO_2	0.18	0.22	0.38	0.70	0.46	0.96	0.70	......
ZrO_2	......	......	......	......	......	......	......	......
P_2O_5	......	0.10	0.22	......	......	......	0.16	......
SO_3	......	0.02	......	......	......	......	......	......
Cl	0.12	0.04	......	......	......	......	......	......
Cr_2O_3	......	......	none	......	......	......	......	......
NiO	......	......	......	......	......	......	......	......
MnO	......	......	0.04	0.20	......	......	0.37	0.55
BaO	0.05	0.29	0.25	......	......	......	......	......
SrO	......	0.06	0.03	......	......	......	......	......
Li_2O	......	trace	......	......	......	......	......	......
	99.86	99.97	100.14	100.46	100.14	100.07	99.28	100.35

LIST OF ROCKS IN TABLE OF ANALYSES.

Rock	Locality	Analyst
1. Trachyte obsidian	Puu Waawaa, Hawaii	W. F. Hillebrand
2. Trachyte	Puu Anahulu, Hawaii	W. F. Hillebrand
3. Glaucophane-sölvsbergite	Cape Ann, Massachusetts	H. S. Washington
4. Hornblende-sölvsbergite	Laugendal, Norway	L. Schmelck
5. Hedrumite	Östö, Norway	V. Schmelck
6. Foyaite	Gran, Norway	L. Schmelck
7. Litchfieldite	Litchfield, Maine	L. G. Eakins
8. Pulaskite	Salem Neck, Massachusetts	H. S. Washington
9. Phonolite	Devil's Tower, South Dakota	L. V. Pirsson
10. Quartz-syenite-porphyry	Bearpaw Mountains, Montana	H. N. Stokes
11. Biotite-trachyte	Yellowstone Park, Wyoming	W. F. Hillebrand
12. Lestiwarite	Laugendal, Norway	V. Schmelck
13. Nordmarkite	Tönsenas, Norway	G. Forsberg
14. Bostonite	Laugendal, Norway	V. Schmelck
15. Pyroxene-syenite	Kunsamo, Finland	N. Sahlbom
16. Riebeckite trachyte	Berkum, Germany	H. Laspeyres

the feldspars and much less abundantly in minute stout prisms. The two most distinct minerals are respectively colorless and clear pale yellow, of strong refraction and double refraction, approximately like diopside or acmite. Extinction is parallel for the colorless prisms and never more than 10° for the yellow ones. There is no visible pleochroism in either, hence lovenite seems to be excluded. The norm of the glassy rock shows the acmite molecule, but no recognizable acmite, aegirite, or riebeckite has been noticed. As the analysis shows zirconia and titanic acid in determinable quantities, it is possible that rare or unknown zirco- or titano-silicates are present. Clear glass and dark globulitic areas are present in small amount.

A glance at this trachytic rock suggests its close relationship with the obsidian of Puu Waawaa. It is not sufficiently fresh, as to its dark constitutents, to warrant full analysis, but the feldspars are only slightly attacked, and a partial analysis by Dr. Hillebrand, given in column 2 of the table, demonstrates sufficiently the practical identity of the two rocks.

The position of the obsidian in the *Quantitative Classification of Igneous Rocks*[1] is shown by the norm calculated from the analysis, which is as follows:

[1] Whitman Cross, Joseph P. Iddings, Louis V. Pirsson, and Henry S. Washington, *Quantitative Classification of Igneous Rocks*, Chicago, 1903.

Orthoclase	29.47	Salic molecules, 86.74
Albite	51.87	$\frac{\text{Sal.}}{\text{Fem.}}=6.92$
Nephelite.	5.40	
Acmite	4.62	Femic molecules, 12.45
Na_2SiO_3	0.61	
Diopside	2.88	
Olivine	2.63	
Fayalite	0.61	
Ilmenite	0.76	
Apatite	0.34	
	99.19	
Etc.	0.62	
	99.81	

As the ratio between salic and femic molecules of this norm is 6.92:1, or slightly less than 7:1, the rock falls within the Dosalane Class. Since the feldspars predominate over nephelite to an extreme degree and there is no anorthite in the norm, the rock falls in the perfelic order *germanare*, and the peralkalic rang *umptekase.* Soda strongly dominates potash, and thus the glass belongs in the subrang *umptekose*, but is so close to the corresponding subrang of the Persalanes that the position is best shown by the name *nordmarkose-umptekose.*

The partial analysis of the trachytoid rock shows that to belong also in the subrang *umptekose.*

Local interest of the discovery.—The discovery of this lava rich in alkali feldspar, so far removed petrographically from the basalts and allied rocks hitherto supposed to be the only products of volcanoes on the island of Hawaii, raises primarily a question of much local interest. The modes of occurrence, described above, suggest that there may have been quite extensive eruptions of these lavas. Unfortunately, these rocks were found just at the close of my visit to the island of Hawaii, and I was unable to search for further occurrences. The terrace-like bench of Puu Anahulu is certainly a remnant of a topography carved out of the trachytic rock, and it may well be that beneath the basaltic flows from Mauna Kea, Mauna Loa, and Mount Hualalai there is an ancient trachytic island. So far as I am aware, however, no fragments of trachyte have been found in the

more recent basaltic lavas. In those of Mount Hualalai I observed only inclusions of dunite, olivine-gabbro, pyroxenite, and basic augite-andesites.

If further exposures of the trachytoid rocks are found, it seems to me probable that they will be in the area of the Waimea plain which extends practically from Puu Anahulu for twenty miles northeasterly to the north base of Mauna Kea, or in the northern and oldest basaltic section of the island, the Kohala Mountains.

Trachytic cones like Puu Waawaa may exist near the bases of Mauna Kea or Mount Hualalai. Their materials, if of the black glass or aphanitic rock described, might naturally be considered as basaltic, if not subjected to chemical examination.

Puu Waawaa has the appearance of being a cone built up by explosive eruption of one short period, like the scores of basaltic cones which dot the slopes of Mauna Kea and Mount Hualalai, and which seem to belong to a period of local volcanism following that of lava outpourings. The materials of Puu Anahulu is agglomerate-like and is certainly not a part of a simple flow, but its crystalline texture shows also that it is not like the tuffs of Puu Waawaa. In all probability, therefore, there was in the comparatively remote past of the island of Hawaii a period of trachytic eruptions of a magnitude not now to be ascertained, but possibly of much importance.

A broader significance of this discovery is connected with the history of the Hawaiian group. While no one of the larger Hawaiian islands has been thoroughly investigated as to the range in composition of the lavas which have built it up, it is hardly probable that trachytoid rocks occur upon them. It is, therefore, highly interesting that the most recent island of the group, Hawaii, should exhibit this unique rock.

In discussion of this question, it must be understood that the island of Hawaii is not only the largest, but is also, in the current view, the youngest, and lies at the extreme southeastern end of a zone of oceanic islands which geologically belong together, extending for fifteen hundred miles or more to the west-northwest, toward the coast of Japan. The larger islands, commonly referred to in speaking of the Hawaiian group, are all located in the eastern end of this zone. The smaller ones, stretching out for more than a thousand

miles, farther, are, in part at least, known to be remnants of former volcanic piles now reduced by erosion in some cases to mere reefs. So far as I have found statements concerning this long train of islets, they are basaltic, excepting the coral-reef rock. The inference drawn by many geologists who have considered the matter is that all these islands are the products of a long cycle of volcanic eruptions producing similar lavas. It appears to me plausible to assume that the earliest eruptions occurred at or near the western limit of this zone, and that, in a general way at least, the centers of activity have developed successively farther and farther to the east or southeast, until now the only active loci of eruption are those of Mauna Loa and Kilauea on the island of Hawaii.

A somewhat different view was taken by J. D. Dana, who has said:

> There is reason for believing that the fires along the Hawaiian line broke out all together at some time in the long past, but only Hawaii has kept on piling up lava streams from that remote time of outbreak until now, and hence has come the altitude of these loftiest volcanic mountains of the Pacific.[1]

Dana recognized, however, that Kauai and Oahu, the most northwesterly of the larger islands, exhibit great erosion. It is also a fact that both these islands are dotted by cinder cones, some of them with craters of model-like form, situated in such independent relation to the topographic forms produced by the great erosion that their later age is unquestionable.

Whatever the point of first eruption may have been, this volcanic cycle began in a remote geologic epoch, not now determinable, but there are grounds for believing that it may well have been in the early part of the Tertiary period. The chief evidence bearing on this point consists in the destruction of the older centers by enormous and long-continued erosion, the existence of the later tuff cones mentioned, and the fact that the raised reef of beach deposits abutting against the Diamond Head crater, on the island of Oahu, contain fossils considered by Dr. W. H. Dall to be of late Pliocene or early Pleistocene age. The crater of Diamond Head, however, is but one of many small centers of tuff eruption, belonging to the comparatively recent and feeble epoch of volcanic activity. Oahu may be, moreover, one of the younger islands of the long Hawaiian chain.

[1] *Characteristics of Volcanoes*, pp. 357, 358.

The magnitude of the erosion by which the mountains and valleys of Kauai and Oahu have been carved out of former basaltic piles cannot now be measured. All writers upon these islands have recognized that erosion has been great. The imposing cliffs or *pali* which face the sea upon both islands, the canyons with walls 2,000–3,000 feet in height, the general ruggedness of mountain contours, are comparable in scale with the same features of the Rocky Mountain country. The erosion periods of the two districts must also be comparable. The former volcanic centers are rudely indicated by the attitude of lava flows, but enormous sections of the old volcanoes have been engulfed by faulting or wholly destroyed by erosion.

The discovery by Dall of marine fossils in a raised reef or beach rock about Diamond Head, the well-known tuff crater near Honolulu, fixes a datum point in the history of Oahu which is manifestly of great importance. Close determination of the age of the fossiliferous deposit is at present impossible because, to quote Dr. Dall,

> we have no standard of comparison in the whole Polynesian region by which the species could be compared with those of Tertiary beds of known age; but the fossils have every characteristic of those generally assigned to the Pliocene or upper Miocene in their general aspect, and state of fossilization. . . . . To sum up, it is concluded that the reef rock of Pearl Harbor and Diamond Head limestones are of late Tertiary age, which may correspond to the Pliocene of west American shores, or even be somewhat earlier.[1]

The view of Dr. Dall that "the whole mass of Diamond Head had been slowly deposited in comparatively shallow water and gradually elevated without being subjected to notable flexure" seems to the writer incorrect for various reasons, some of which have been pointed out by Dr. J. C. Branner[2] and Dr. S. E. Bishop.[3] This point is not here at issue, for whatever the relations of the marine deposits to the Diamond Head tuffs, they exist and are younger than the great erosion of Oahu. Even if of early Pleistocene date, they indicate that the enormous denudation of the Oahu volcanoes must be referred to the late Tertiary and the lava eruptions themselves to a still earlier period.

From the considerations above presented it appears that the

[1] *Loc. cit.*, pp. 58, 60.

[2] *American ournal of Science*, Vol. XVI (1903), pp. 306, 307.

[3] *American Geologist*, January, 1901.

Hawaiian volcanic province was characterized by basaltic or allied lavas for a very long geologic period, and that in comparatively recent times the first highly siliceous and feldspathic magma appeared. Even now the basaltic emissions continue with no known recurrence of the trachytic magma.

General significance of the occurrence.—The long sequence of basaltic or allied lavas, which has probably occupied a long geologic period, is in striking contrast with the succession of widely differing lavas, ranging from highly siliceous and alkalic rocks like rhyolite or trachyte, to basic basalts, produced during the same time in various continental provinces adjacent to the Pacific Ocean. To be sure, there is much greater variety in the dark Hawaiian lavas than is implied in the common term given them, but this trachytic magma is certainly highly exceptional, if indeed there has ever been another eruption of equally salic material in the history of the group.

To the modern petrographer this occurrence must at once suggest many interesting problems of petrogenesis. One of these will be the query as to whether magmatic differentiation has produced this unusual lava or not. The extreme advocates of this process, concerning which so much has been assumed and so little proved, will no doubt treat it as a matter of course that this magma, so exceptional for the Hawaiian province, is one of the complementary products of differentiation. This view has, however, not much to support it in the history of the older centers, and until further examination of the chemical characters of the "basalts" of this province have been made elaborate discussion of this point has no good foundation. It remains a matter for speculation as to why the process of differentiation has not long ago produced a greater variety of lavas, or, assuming that the differentiation has taken place, why the products have not been emitted at the more recent centers of volcanic activity. Directly connected with these questions arises also that of possible fundamental differences between the subjacent magmas of the Hawaiian and the continental provinces.

In all of these problems the relations of the Hawaiian trachyte to similar rocks of other localities will be of use. The table already presented gives a series of analyses of allied rocks, and in that following are the norms calculated from those analyses. The latter table

brings out the fundamental chemical relations of these varied rocks and their positions in the *Quantitative System of Classification.* The current names assigned to these rocks are those of the authorities quoted.

The nordmarkose-umptekose rock of Hawaii is shown by the table to be nearly akin in its chemical characters to other rocks of varying occurrence and texture in widely separated parts of the world. The textural differences and those due to the distinguishing rôles played by quantitatively subordinate constituents have led to a variety of names, obscuring the fundamental similarity of the magmas.

Considering the trachyte of Puu Waawaa as a possible differentiate of an underlying parent magma, it is interesting to note that the associations of the chemically similar rocks of the table are widely different. Several of the rocks compared belong in the grorudite-tinguaite series described by Brögger from the Christiania region of Norway.[1] Others are from the similar petrographic province of

NORMS OF ROCKS COMPARED WITH THE HAWAIIAN TRACHYTE.

	MOLECULES OF NORM	UMPTEKOSE				
		"Foyaite" (Brögger) Gran, Norway	"Hornblende sölvsbergite" (Brögger) Laugendahl, Norway	"Hedrumite" (Brögger) Östö, Norway	"Glaucophane sölvsbergite" Cape Ann, Mass. (Washington)	"Trachyte" Puu Waawaa
SALIC MOLECULES	Corundum	....	....	....	....	....
	Quartz	....	....	....	2.0	....
	Orthoclase	23.9	31.1	32.2	30.0	29.5
	Albite	50.3	55.0	46.1	53.4	51.9
	Nephelite	7.4	....	4.5	....	5.4
	Anorthite	4.4	....	0.8	....	....
FEMIC MOLECULES	Acmite (& Na_2SiO_3)	....	4.6	....	6.9	5.2
	Other silicates	7.2	5.0	10.7	6.5	5.5
	Oxides of iron, etc	4.9	4.3	3.7	1.6	1.1
	Apatite	....	....	....	....	....
	Titanite, etc	....	....	....	....	....
Total salic molecules		86.0	86.1	84.6	85.4	86.8
Total femic molecules		12.1	13.9	14.4	15.0	12.5

[1] *Die Eruptivgesteine des Kristianiagebietes,* "Die Gesteine der Grorudit-Tinguait-Serie" (Kristiania, 1894).

NORMS OF ROCKS COMPARED WITH THE HAWAIIAN TRACHYTE—(*Cont'd*)

	MOLECULES OF NORM	NORDMARKOSE									
		"Bostonite" (Brögger) Hedrum, Norway	"Nordmarkite" (Brögger) Tönsenäs, Norway	"Lestiwarite" (Brögger) Laugendahl, Norway	"Pyroxene-syenite" (Hackmann) Finland	"Riebeckite trachyte" (Rosenbusch) Berkum, Germany	"Biotite-trachyte" (Hague & Jagger) Yellowstone Park	"Quartz-syenite-porphyry" (Weed & Pirsson) Bearpaw Mountains, Montana	"Phonolite" (Pirsson) Devil's Tower, South Dakota	"Pulaskite" (Washington) Salem, Massachusetts	"Litchfieldite" (Bayley) Litchfield, Maine
SALIC MOLECULES	Corundum	1.2	....	....	....	....	....	....	....	....	2.9
	Quartz	....	....	4.7	....	4.5	2.8	5.3	....	....	....
	Orthoclase	31.7	35.0	32.8	35.6	32.8	32.8	33.9	27.2	31.1	28.4
	Albite	55.0	48.2	52.4	52.4	53.5	52.9	51.9	54.0	59.2	52.4
	Nephelite	....	5.4	....	2.0	....	....	....	10.5	1.1	10.2
	Anorthite	3.2	....	....	....	....	4.4	....	1.1	2.0	1.7
FEMIC MOLECULES	Acmite (& Na_2SiO_3)	....	1.4	6.0	0.5	3.7	....	2.8	....	....	....
	Other silicates	0.6	8.3	1.5	6.7	3.3	1.6	3.0	2.9	1.8	3.1
	Oxides of iron, etc.	5.4	0.9	0.5	1.2	1.4	4.0	1.3	2.4	4.7	0.7
	Apatite	....	....	....	....	....	....	....	....	....	....
	Titanite, etc.	....	....	1.2	....	....	....	....	....	....	....
Total salic molecules		91.1	88.6	89.9	90.0	90.8	92.9	91.1	92.8	93.4	95.6
Total femic molecules		6.0	10.6	9.2	8.4	8.4	5.6	7.1	5.3	6.5	3.8

Essex county, Mass., where there is a great variety of rocks, discussed in their genetic relations by Washington.[1] No one of the rocks of the table occurs in an association comparable with that of the Hawaiian trachyte. The occurrence here described seems to be a notable one, requiring consideration from the advocates of the view that a natural or genetic classification of igneous rocks may be worked out from the study of their associations. The recent tabulations of chemical analyses of igneous rocks by Washington[2] and Iddings,[3]

[1] "The Petrographic Province of Essex County, Mass.," *Journal of Geology*, Vols. VI and VII (1898, 1899).

[2] "Chemical Analyses of Igneous Rocks, 1884–1900," *Professional Paper No. 14* (1903), U. S. Geological Survey; "The Superior Anlayses of Igneous Rocks from Roth's Tabellen, 1869–1884," *Professional Paper No. 28* (1904), U. S. Geological Survey.

[3] "The Chemical Composition of Igneous Rocks, Expressed by Means of Diagrams, etc.," *Professional Paper No. 18* (1903), U. S. Geological Survey.

according to the *Quantitative System*, bring out many similar significant facts, to be taken into account in this discussion. They show the essential identity of many magmas having widely different associations, and indicate that the designation of a given rock or magma as belonging in the train (*Gefolgschaft*) of certain parent magmas can at most be true only of certain peculiar or aberrent modifications, as a complete statement available for systematic classification.

WHITMAN CROSS.

PHYSIOGRAPHIC PROBLEMS OF TODAY.[1]

In looking ahead and endeavoring to see in what ways our knowledge of the earth's surface can be increased, the fact should be borne in mind that physiography is one of the younger of the sciences. In truth, the new geography, or physiography as it has been christened, is of such recent birth that its limits and its relationship to other sciences are as yet in part, indefinite. Accepting the conservative view, that physiographers should confine their studies to the earth's surface, but have freedom to investigate the causes producing changes of that surface, whether coming from without or arising from forces at work within the earth, my task is to suggest ways in which man's knowledge of his dwelling-place may be enlarged.

INHERITANCES.

Although the scientific study of the earth's surface can with sufficient accuracy be said to be less than a century old, and to have attained the greater part of its growth during the past half-century, the fact must be freely admitted that, preceding the recognition of physiography as one of the sisterhood of sciences, there was a long period of preparation during which man's physical environment, and the many changes to which it is subject, attracted attention and awakened interest. The more or less general and diffuse descriptions of the earth's surface embraced under the term "physical geography," when vivified by the idea of evolution, became the more definite and concrete physiography of today. Physiography from this point of view may perhaps be justly designated as scientific physical geography. New thoughts grafted on the previously vigorous stem have borne rich fruits, but in many instances inherit much of their flavor from the original trunk. One of the important duties of the physiographer is to select all that is of value from the inheritance that has come to him, whether of fact, or theory, or suggestion and give it a place in his systematically classified records.

[1] Read before the section of Physiography, International Congress of Arts and Science, Universal Exposition, St. Louis, September 21, 1904.

In the physical geographies on our library shelves, in books of travel, in transactions of learned societies, etc., pertaining to the era preceding the time when physical geography became a science, there are numerous records of facts, concealed perhaps in part in dreary cosmogonies and exuberant theories, which in many instances are of exceptional value because, in part, of the date at which they were observed. One of the leading ideas in scientific geographical study is the recognition of the wide-reaching principle that changes are everywhere in progress. Many, if not all, of the changes referred to have an orderly sequence, and constitute what may be suggestively termed life-histories. In writing the biographies of various features of the earth's surface the observations made a century, or many centuries, ago have a peculiar, and in some instances an almost priceless, value, because of the light they furnish as to the sequence of events. In this and yet other ways the records left by past generations of geographical explorers contain valuable legacies. In attempting to winnow the wheat from the chaff of physical geography, the physiographer should avoid the conceit of youth, and fully recognize the work of the bold and hardy pioneers who blazed the way for the more critical and better-equipped investigators who came later.

NOMENCLATURE.

One of the reasons for the slow growth of knowledge concerning the earth's surface during the centuries that have passed was the fact that the objects which claimed attention were, to a great extent, designated by terms derived from popular usage. The language of geography, in large part of remote antiquity, was adopted from the parlance of sailors, hunters, and others in the humbler walks of life, and retained its original looseness of meaning. The change from geographical description to scientific analysis, which marked the birth of physiography, necessitated greater precision in the use of words. This change is not yet complete, and physiography is still hampered in its growth and usefulness by a lack of concrete terms in which tersely and accurately to state its results. In the nomenclature of physiography today the words inherited from physical geography by far outnumber the technical terms since introduced, and to a large extent still retain the indefiniteness and lack of precision that charac-

erize the multiple sources from which they were adopted. One of the pressing duties of the scientific student of the earth's surface, and one which on account of its many difficulties may well be reckoned among the physiographic problems of today, is the giving of fixed and precise meanings to the words employed in describing and classifying the features of the earth's surface A scientific physiographical nomenclature is of importance, not only to the special students of the earth's surface, but through them to communities and patrons. The diverse interpretations that have been given to such seemingly simple terms as "shore," "lake," "river," "hill," "mountain," "divide," etc., as is well known, have led to misunderstandings, litigations, international disputes, and even threatened to bring on war between highly civilized nations. A duty which physiographers owe, not only to their science in order that its continued advancement may be assured, but to communities in payment for the terms borrowed from them, as well as for the general good, is a systematic effort accurately to define the words and terms now used to designate the features of the earth's surface. Careful attention needs to be given also to the coinage of new terms when their need is definitely assured. An appropriate task for a group of physiographers would be the preparation of a descriptive geographical dictionary, suited to the wants of both the specialist and the layman.

While considering the advantages of a language of science, its disadvantages should also be recognized.

The histories of all sciences show that, as they became more and more precise, and as their nomenclature grew so as to meet their internal requirements more and more completely, they at the same time, on account of the very precision and accuracy of their language, became more and more circumscribed and farther and farther removed from the great mass of humanity for whose use and benefit they exist. Not only this, but a science dealing with facts of vast public importance and filled with instructive and entertaining matter—nay, in itself even poetic and as fascinating as the pages of a story-book—has, in not a few instances, been rendered difficult to understand, and even repellant to the general reader, by a bristling array of esoteric terms built about it like an abatis.

Between the two extremes—on the one hand, a science without

words in which to speak concisely and accurately, the condition in which the physiographer finds himself at the present time; and, on the other hand, a science with a language so technical and abstruse that it seems a foreign tongue to the uninitiated—is there not a happy mean? Such a much-to-be-desired end seems to be within the grasp of the physiographer. By giving precision to, and defining the bounds of words inherited from physical geography, and adding to the list such terms as are strictly essential in the interest of economy of time and space, or for accuracy—such contributions, so far as practicable, to be chosen from the language of everyday life—it would seem as if a nomenclature could be formulated which would at the same time meet the requirements of the scientific student and enable the general reader of average intelligence to receive instruction and inspiration from the talks and writings of the especially qualified interpreters of nature.

EXPLORATION.

Physiography, to a great extent, is still in the descriptive stage of its development, but the descriptions demanded are such as discriminate and select the essential, or suggestive, from the confusing wealth of secondary details frequently present. The records should also include comparisons between the objects described and analagous topographic or other physiographic features, and, within safe and reasonable limits, be accompanied by explanations of their origin and life-histories.

One of the important functions of physiography, as a more mature growth of physical geography, is to continue and render more complete the exploration of the earth's surface and to conduct resurveys where necessary. Geographical exploration has, as is well known, been carried on viogrously, although spasmodically, in the past, and the areas marked "unknown" on our globes have become smaller and smaller, and more and more isolated. The more critical physiographic studies, however, which have for their object not only the description of coast lines, mountain ranges, plains, etc., but a search for the records of their birth, the discovery of their mode of development and their assignment to a definite place in the complex whole, termed man's environment, has progressed but slowly. In this stricter sense, the unknown areas on the earth's surface embrace regions of continental

extent. It is this latter method of geographical exploration and survey which now demands chief attention.

The terms "exploration" and "survey" are here used advisedly, as two divisions of physiographic field-work may justly be recognized. These are: first, travel in which physiographic observations are incidental to other aims, or perhaps the leading purpose in view, as during a physiographic reconnaissance; and, second, detailed surveys and critical study of definite areas or of concrete problems. Each of these subdivisions of the great task of making known the beauties and harmonies of man's dwelling-place has its special functions.

From the observant traveler we expect comprehensive and graphic descriptions of the regions visited, rendered terse by the use of well-chosen terms, in which the more conspicuous elements of relief, and other physiographic features, and their relation to life, shall be clearly and forcibly presented. In order to render this service, the traveler should not only be familiar with the broader conclusions and fundamental principles of physiography, but skilled in the use of its nomenclature. The chief contribution to the science of the earth's surface demanded of the explorer of new lands is a careful record of facts. When a journey becomes a reconnaissance with physiography as its leading feature, it is not only an advance into a more or less unknown region, but an excursion into the realm of ideas as well. It is during such explorations, when one's mind is stimulated by new impressions, that hypotheses spring into existence with greatest exuberance. While most of these springtime growths are doomed to wither in the more intense heat of subsequent discussion, their spontaneity, and the fact that the mind when not oppressed by a multitude of details grasps significant facts almost by intuition, make the suggestions of the explorer of peculiar value.

The detailed work of physiographic surveys falls into two groups: namely, the study of definite areas, and the investigation of specific problems. In each of these related methods the desirability of recording facts by graphic methods is apparent. The demand for accurate maps as an aid to both areal physiography and the study of groups of specific forms, or the functions of concrete processes, needs no more than a word at this time. With the growth of physiography the time has come when the work of the individual explorer, who from force of

circumstances endeavors to follow many of the paths he finds leading into the unknown, is replaced to a large extent by well-organized and well-equipped scientific expeditions. It is to such systematically planned campaigns, in which the physiographer and representatives of other sciences mutually aid each other, that the greatest additions to man's knowledge of the earth's surface are to be expected. The most extensive of the unexplored or but little-known portions of the surface of the lithosphere, in which a rich harvest awaits the properly equipped expedition, are the sea-floor and the north and south polar regions. As is well known, splendid advances have been made in each of these fields, but, as seems evident, much more remains to be accomplished.

In the branch of physiography appropriately termed "oceanography" the problems in view are the contour of the sea-floor, or its mountains and deeps, plains and plateaus, the manner in which each inequality of surface came into existence, and the various ways it is being modified. In both of these directions the interests of the physiographer merge with those of the biologist and the geologist. One phase of the study of the ocean's floor which demands recognition is that the topographic forms there present are such as have been produced almost entirely by constructional and diastrophic agencies, free from complications due to erosion which so frequently obscure the result of like agencies on the land. For an answer to the question: What would have been the topography of land areas, had there been no subaërial decay and denudation? the topography of submarine regions furnishes at least a partial answer. The sounding line in the Caribbean region has furnished examples of topography due, as it seems, mainly to differential movements of blocks of the earth's crust bounded by faults, which have not been modified by subaërial denudation. In a similar way, as is to be expected, a survey of other portions of the at present water-covered surface of the lithosphere will supplement our knowledge of the emerged portions of the same rock-envelope, and assist in an important way in the deciphering of their histories.

In the Arctic and Antarctic regions, where all is unknown, systematic research may be expected not only to extend many branches of physiographic study, but to bring to the front as yet unsuspected problems.

The larger of the unexplored regions of the earth, however, are not

the only portions of our field of study that demand attention. New ideas, new principles, and fresh hypotheses make an unknown country of the most familiar landscape. The definite formulation of the base-level idea, the suggestive and far-reaching principle embraced in the term "geographic cycle," the planetesimal hypothesis as to the origin of the earth, etc., furnish new and commanding points of view, or, as they may be termed, primary stations in the physiographic survey of the earth's surface by means of which previous local surveys may be correlated and corrected.

In the search for problems, the unraveling of which may be expected to advance the scientific study of the earth's surface, the writings of travelers, the pregnant suggestions of those who make reconnaissances into the realm of unknown facts and of unrecognized ideas, as well as the precise and accurate pictures of portions of the earth's surface presented on the maps of the topographer and the charts of the oceanographer, point the way to still greater advancements, and furnish inspiration to those who follow.

FUNDAMENTAL CONCEPTS.

While physiography deals with the surface features of the earth, the fact that in those features is expressed to a great extent the effects of movements originating deep within the earth, leads the student of continents and oceans to ask of the geologist and the physicist puzzling questions as to the changes that are taking place in the great central mass of our planet, and even in reference to the origin of the earth itself. So intimately are the various threads of nature-study interwoven that the full significance of many of the surface features of the earth cannot be grasped and their genesis explained until the nature and mode of action of the forces within the earth which produce surface changes are understood.

The growth of physiography up to the present time has been largely influenced by the far-reaching ideas of Laplace and others in reference to the nebular origin of the solar system. In all of the questions respecting secular changes of land areas in reference to the surface level of the ocean, the origin of corrugated and of block mountains, the fundamental nature of volcanoes, etc., the controlling idea has been that the earth has cooled from a state of fusion, and is

still shrinking on account of the dissipation into space of its internal heat.

With the recent presentation of the planetesimal hypothesis by Professor Chamberlin, a radically different point of view is furnished from which to study the internal condition of the earth. The new hypothesis—which has for its main thesis the building of a planet by the gathering together of cold, rigid, meteoric bodies, and the compression and consequent heating of the growing globe by reason of gravitational contraction—is suggestive, and seems so well grounded on facts and demonstrated physical and chemical laws that it bids fair not only to revolutionize geology, but to necessitate profound changes in methods of study respecting the larger features of the earth's surface. One of the several considerations which make the planetesimal hypothesis appeal forcibly to the inquiring mind is that it employs an agency now in operation, namely, the process of earth-growth through the incoming of meteoric bodies from space; and for this reason is welcomed by uniformitarians, since it is in harmony with their understanding of a fundamental law of nature.

In many, if not all, questions respecting the origin of the atmosphere, the ocean, continents, mountains and volcanoes, and the secular, and to a marked extent in certain instances, the daily changes they experience, it is evident that the planetesimal hypothesis necessitates a revision, or at least a review, of some of the fundamental conceptions held by physiographers. The objection will perhaps be advanced that to make such a radical change of front on the basis of a young and as yet untried hypothesis is not wise. The reply is that the older hypothesis has been tried and to a marked extent found wanting, and that the new conception of the mode of origin of the earth demands consideration, not only as affecting a large group of basement principles of interest to the physiographer, but with the view of testing the planetesimal hypothesis itself by physiographic standards.

The problems interlocked with the mode of origin of the earth, in which the physiographer shares an interest with the geologist, are the rate at which the earth's mass is now being increased owing to the ingathering of planetesimal, and the chemical and physical and perhaps life conditions of the incoming bodies; the temperature of the earth's interior, and the surface changes to be expected from its

increase or diminution; the results of gravitational contraction in reference to movement in the earth's crust; the extrusion of gases and vapors from the earth's interior, and the resultant changes in progress in the volume and composition of the atmosphere and hydrosphere. In these and still other fundamental conceptions of the primary causes of many of the changes in progress on the earth's surface the planetesimal hypothesis seemingly furnishes the cornerstone of a broader physiography than has as yet been framed.

IDEAL PHYSIOGRAPHIC TYPES.

During the descriptive stage of the study of biology the relationships among plants and animals were the chief end in view, and as a result of the conditions confronted, a systematic classification of animate forms under species, genera, families, etc., was formulated, which has been of infinite assistance during the more philosophical investigations that followed. Biological classification was facilitated, as learned later, by the fact that with the evolution of species there was concurrent extinction of species. As the tree of life grew, its branches became more and more widely separated.

Throughout the many changes the surface features of the earth have experienced there has also been development, not of the same grade, but analagous to that recognized in the realm of life; but the process of extinction has been far less complete than in the organic kingdom, and the connecting links between the various groups of topographic and other physiographic forms produced have persisted, and to a conspicuous extent still exist. The task of arranging the infinitely varied features of the earth's surface in orderly sequence, or systematic physiography, is thus far more difficult than the similar task which the flora and fauna of the earth present.

The utility of classification is fully recognized by physiographers, and various attempts have been made from time to time to meet the demand, but thus far without producing a generally acceptable result. Remembering that a scheme of classification of topographic and related forms is to be considered as a means for attaining a higher end, namely, the history of the evolution of the surface features of the earth, and should be of the nature of a table of contents to a systematically written treatise, the task of preparing such an index

becomes of fundamental importance to the physiographer. Since extinction of species among physiographic features has probably not occurred, and connected series of forms which grade one into another confront us, the practical lesson taught by the success of schemes of biological classification seems to be that ideal physiographic types should be chosen correlative with species among plants and animals.

By "ideal physiographic types" is meant complete synthetic examples of topographic and other physiographic forms, which will serve the rôle of well-defined species in the study of the surface features of the earth. Ideal types may be likened to composite photographs. They should combine critical studies of many actual forms, within a chosen range, and in addition be ideally perfect representatives of the results reached by specific agencies operating under the most favorable conditions. Like the idealized personalities of history and religions, the types of physiographic forms might well be more perfect than any actual example. When such idealized types shall have been chosen after careful study, described with care, and illustrated by means of diagrams, maps, pictures, models, etc., a comparison with them of actual examples on any portion of the earth for the purpose of identification and classification would be practicable. A well-arranged catalogue of ideal types would be an analytical table of contents to the history of the evolution of the features of the earth's surface, and constitute a scheme of physiographic classification.

In illustration of what is meant by an idealized physiographic type: We find in nature a great variety of alluvial deposits, now designated as alluvial cones or alluvial fans. They present a wide range and infinite gradations in size, shape, composition, structure, angle of slope, degree of completeness, stage of growth or decadence, etc. Complications also arise because of the association and intergrowth of such alluvial deposits with other topographic forms. In constructing the ideal type the characteristics of many of the most perfect actual alluvial cones, aided by a study of the essential features of similar artificial structures, should be combined in an ideally perfect and representative example which would serve as the type of its specie. All actual examples might be compared with such a type, their specific and generic relations determined, and their individual variations noted. In like manner, other topographic forms, ranging

from the more concrete species—such as constructional plains, cinder cones, sea cliffs, river terraces, etc.—to the more complex forms—as, for example, mountain ranges, mountain systems, and yet larger earth-features—could be represented by ideally perfect examples free from accidental and secondary complexities and accessories.

While individual examples of idealized topographic and other features of the earth's surface would serve as species, their arrangement under genera, families, etc., offers another problem, in which relationship or genesis should be the controlling idea.

The selection of idealized physiographic types, as just suggested, has for its chief purpose the reduction of endless complexities and intergradations to practicable limits. It is a method of artificial selection so governed that, while no link in the chain of evolution need be lost to view, certain links are chosen to represent their nearest of kin and serve as types. A danger to be marked by a conspicuous signal, in case this plan for aiding physiographic study is put in practice, is that it may tend toward empty ritualism. To give the idealized types chosen for convenience of classification an appropriate atmosphere, the fact that changes are constantly in progress—that mountains come and go even as the clouds of the air form and reform—should be ever present in the mind.

The process of evolution without concurrent extinction which characterizes the development of physiographic features finds expression also in related departments of nature, as, for example, in petrography, where, as is well known, it has greatly delayed the framing of a serviceable and logical system of classification. Indeed, the principle referred to may be said to be one of the chief distinctions between the organic and the inorganic kingdoms of nature.

THE PRIMARY FEATURES OF THE EARTH'S SURFACE.

The primary features of the earth's surface may consistently be defined as those resulting from the growth and internal changes of the lithosphere, while the modifications of relief resulting from the action of agencies which derive their energy from without the earth may be termed secondary features. The primary or major characteristics of the earth's surface, so far as now known, may be ranked in three groups, in accord with the agency by which they were principally

produced; namely, diastrophic, plutonic, and volcanic physiographic features. Each of the groups presents many as yet unsolved problems.

Diastrophic features.—Under this perhaps unwelcome term are included a large class of elevations, depressions, corrugations, faults, etc., in the surface portion of the lithosphere due to movements within its mass. The causes of the changes which produced these results are as yet obscure, and, although a fruitful source of more or less romantic hypotheses, may in general terms be referred to the effects of the cooling and consequent shrinking of a heated globe, or, under the terms of the planetesimal hypothesis, reckoned in part among the results of gravitational condensation. However obscure the fundamental cause, the results in view are real, and among the larger of the earth's features with which the physiographer deals. They are the greater of the quarry blocks, so to speak, which have been wrought by denuding agencies into an infinite variety of sculptured forms. Included in the list, as the evidence in hand seems to indicate, are continental platforms, oceanic basins, corrugated and block mountains, and many less mighty elements in the marvelously varied surface of the lithosphere. Not only the study of the shapes of these features of the earth's surface, but the movements they are still experiencing, and their transformations through the action of denuding agencies, claim the attention of the physiographer. While it may be said that the investigation of the method by which the primary relief of the lithosphere have been produced, falls to the lot of the geologist or the geophysicist, the physiographer is also interested in the many profound problems involved. The geologist and physiographer here find a common field for exploration, and can mutually assist each other. The task of the physiographer is to describe and classify the elements in the relief of the lithosphere due to diastrophic agencies, discriminate them from deformations due to other causes, and restore so far as practicable the forms that have been defaced by erosion. He can in this way assist the geologist by presenting him with the results of diastrophism free from accessories. With pure examples of the forms produced, the geologist will be better able to discover the causes and their mode of action, which have produced the observed results.

Although much has been accomplished in the way of determining which elements in the relief of the lithosphere are due to diastrophic

agencies, only a small part of the difficulties to be overcome have been met. The aim in view is the attaining of a knowledge of what would have been the shape and surface features of the solid earth, had there been no modifications by internal causes except diastrophism, and no changes in relief by erosion or other surface agencies. Included in this branch of physiography is the shape of the earth itself, in the study of which the physiographer became a geodesist. The earth's shape, and its primary surface features due to diastrophism, form the logical basis for physiographic study, in which ideal types of topographic forms declare their usefulness. In the geographical museums of the future, at the head of the long series of models of physiographic types illustrating the species, genera, families, etc., of the earth's surface features, should be placed ideal examples of the most typical elements of relief due to diastrophism.

Physiographers cannot rest content with the study of the shape of the lithosphere and of its surface relief, in which so much of the history of the earth is recorded, and refrain from searching for the deeper meanings these facts suggest, but must have freedom to invade the province of the geologist, the astronomer, the physicist, the chemist, and other subdivisions of the science of the cosmos, in search of truths bearing on his special line of work. This is particularly true in connection with the special department of physiography in hand, in which many of the branches of the river of knowledge have their sources.

Plutonic features.—Intimately associated with the irregularities of the earth's surface due to a decrease in its volume, and, as our reasoning tells us, dependent primarily on the same cause and at present only partially differentiated from them, are surface elevations and depressions, produced by the migration of portions of the earth's central magma from the deep interior toward or to the surface. A convenient but arbitrary subdivision of the matter forced outward from the earth's interior is in vogue among geologists, and rocks of plutonic and of volcanic origin are recognized. To the physiographer the distinction referred to is more suggestive than it appears from the point of view of the geologist, since the recognition of differences between topographic forms produced by the injection of fluid or plastic magmas into the cooled, rigid outer portion of the earth, and

topographic forms resulting from the extrusion of similar matter at the surface, is of genetic significance.

The simile was used above between the quarry blocks taken to the studio of the sculptor and the portions of the earth's surface brought by diastrophic movements within the sphere of influence of denuding agencies. There are two other primary classes of physiographic quarry blocks; one produced by intrusions of highly heated plastic or fluid magmas into the earth's crust, which cause upheavals of the surface above them, and the other due to extrusions of similar material at the surface, as during volcanic eruptions. The first of these two series of earth-features has received much less attention from physiographers than the second series.

Surface elevations due to local intrusions are well illustrated by the reconstructed forms of the Henry Mountains and the similar information in hand concerning several other regions. The topographic forms referred to have a conspicuous vertical measure in comparison with their breadth of base, and their prominence gained for them earlier recognition than in the case of related, and in part far more important, plutonic changes. It is to be remembered, however, that every intrusion of a magma into the earth's crust is, theoretically at least, accompanied by a change in the relief of the surface above. What surface changes accompany the lateral movements in the rocks invaded by a dike has eluded search and seemingly escaped conjecture. The surface changes produced by an extensive horizontal injection of a magma, as when intruded sheets are found in stratified terranes, is a matter of inference rather than of observation. Intrusive sheets are numerous, and the surface changes in topography, and consequently of drainage, that accompanied their production must have been important, but definite examples are wanting. Critical studies are needed in this connection, both by physiographers and by geologists, in order that the widely extended movements which have been observed in the surface of the lithosphere may be referred to their proper cause. How do we know, for example, that the many recorded changes in the relation of the land to sea-level may not in part be due to the injection of magmas into the earth's crust, instead of diastrophic movements as commonly supposed. The activity of volcanoes at the present day is warrant for the hypothesis that the concurrent process of sub-

surface injection is still in progress, and is today producing changes in the geography of the earth's surface.

Of still more importance to the physiographer than the surface changes known, or legitimately inferred, to have resulted from the formation of dikes, laccoliths, and intruded sheets are the elevations and possibly concurrent depressions of the surface of the lithosphere caused by still greater migrations of portions of the earth's central magma outward and into or beneath the rigid surface rind. Concerning these *regional intrusions*, as they may be termed, the geologist has furnished suggestive information. We are told, for example, that the granitic rocks from which the visible portion of the Bitter Root Mountains in Idaho have been sculptured are intrusive. The now deeply dissected granitic core of this mountain range measures not less than three hundred miles in length and from fifty to over one hundred miles in width. The area occupied by intrusive granitic rocks in the Sierra Nevada is seemingly still greater than in the case just cited, and other regional intrusions of even mightier dimensions are known in the vast region of crystalline rocks in Canada and elsewhere. The covers of sedimentary or other material which formerly roofed these vast intrusions in the instances now open for study have for the most part been removed by denudation, although instructive remnants of metamorphosed terranes occurring as inliers in the granitic areas sometimes persist and reveal something of the nature of original domes of which they formed a part.

The surface changes in relief produced by the migration of magmas measuring thousands, and in many instances, as we seem justified in concluding, tens of thousands, of cubic miles, from deep within the earth outward, but failing to reach the surface, must be reckoned as of major physiographic importance. The very magnitude of the features of the earth's surface due to such intrusions has served to conceal their significance. We look in vain in our treatises on physiography for so much as a mention of them. Perhaps the excuse will be offered that the modifications in relief referred to are commonly grouped with the results produced by diastrophic agencies; but, if so considered, a differentiation seems necessary, and the significance of the topographic forms resulting from intrusions of various kinds clearly recognized.

In our dreamed-of museum of ideal physiographic types, mighty domes raised by regional intrusions, broad uplifts with perhaps sharply defined boundaries, elevated by relatively thin intruded sheets, as well as steep-sided domes with relatively small bases, concealing laccoliths, and the still smaller covers arching over plutonic plugs, will demand a place in the group of type examples of primary unsculptured elements in the relief of the lithosphere.

Volcanic features.—Elevations on the surface of the lithosphere due to the presence of material extruded from volcanic vents have long been recognized, but the specific, or, as perhaps may be consistently claimed, generic, differences among them has only recently claimed attention. Of primary importance in the classification of topographic forms of volcanic origin is the fact that volcanoes are both constructive and destructive in their action. Among the results of constructive action are included the changes produced by effusive, fragmental-solid, and massive-solid eruptions, each of which has furnished a wide range of primary topographic forms. The catalogue of recognized types includes lava plains and plateaus, cinder and lapilli cones, lava cones and domes, lapilli and dust plains, together with many minor structures, such as "spatter cones," "lava deltas," "lava gutters," "lava levees," and the various surface details of lava streams due to the flow of still mobile magmas beneath a stiffened crust which ranged in physical consistency from a highly plastic to a rigid and brittle condition. With these more familiar forms are to be included also the results of massive-solid extrusions, of which the "obelisks" of Mont Pelé are the most striking examples.

Our present list of destructional topographic forms due to volcanic eruptions includes decapitated cinder, lapilli and lava cones, and subsided and broken lava domes, calderas, crater rings, etc., together with cones of various kinds breached by outflowing lavas; and, as minor features, the floated blocks sometimes carried on lava streams, or the *moraines of lava flows*, as they may suggestively be termed, the subsided and broken roofs of lava tunnels, etc.

The interesting contributions made during the past decade to the list of topographic forms resulting from the action of volcanic agencies are highly suggestive, and warrant the belief that still more numerous and equally important results in the same direction will reward more

extended and more careful search. The progress of physiography would evidently be accelerated by a systematic review and a more definite classification of the topographic forms, both constructional and destructional, known to have resulted from volcanic agencies, and a more critical selection of types to serve as species than has as yet been attempted. From such a catalogue something of the underlying principles governing the many ways in which the relief of the earth's surface has been modified, and is still being changed through the agency of volcanoes, would make themselves manifest, and predictions rendered possible which would facilitate further study. The analogy between lava streams and rivers, on the one hand, and glaciers, on the other, suggests interesting and instructive methods for considering the entire question of the movements of liquids and solids on the earth's surface.

While the topographic changes produced by volcanic agencies are of chief interest to the physiographer, they lead him to profound speculations in reference to the nature of the forces to which they are due, the source and previous condition of the matter extruded during eruptions, and the study of the existing relations between the earth's interior and its surface. The great, and as yet but partially answered, questions: Whence the heat manifest during volcanic eruptions? What is the source of the energy which forces lava to rise from deep within the earth through volcanic conduits to where it is added to the surface, perhaps ten to twenty thousand feet above sea-level? and, what is the source or sources of the steam discharged in such vast quantities during eruptions of even minor intensity? are as of great interest to the physiographer as they are to the geologist, and furnish another illustration of the unity of nature-study. From the new point of view furnished by the author of the planetesimal hypothesis, the many questions the physiographer is asking concerning volcanoes and fissure eruptions are rendered still more numerous by the suggestion that these fiery fountains are the sources from which the ocean and all the surface waters of the earth have been supplied. This startling revelation, as it seems, makes a still more urgent demand than had previously been felt for quantitative measures of the vapor discharged from volcanic vents. Nor is this all; with the steam of volcanoes is mingled various gases, and the mode of origin of the

earth's atmosphere as well as the changes it is now undergoing, is a theme in which the physiographer is profoundly interested.

Volcanic mountains are numbered among the most awe-inspiring of topographic forms; the solid additions which volcanoes make to the surface of the lithosphere are in view, and the contributions to the atmosphere of vapors and gases from the same sources are tangible facts; but another phase of the great problem is also of interest to the physiographer, namely, what changes take place in the rigid outer shell of the earth by reason of the transfer of such vast volumes of material as are known to have occurred from deep within the earth to its surface. The magmas which have been caused to migrate and come to rest for a time, either as intrusions within the earth's outer shell, or as extrusions on its surface, are measurable in millions of cubic miles. In connection with the profound questions concerning the formation of folds and fractures in the earth's crust, an agency is thus suggested comparable in importance with loss of heat, as under the nebular hypothesis, or with gravitational compression, as explained by the planetesimal hypothesis. In the many discussions that have appeared as to the adequacy of earth contraction to account for the origin of mountains of the Appalachian type, I have been able to find but one mention of the rôle played by the transfer of matter from deep within the earth outward, and in part its extrusion at the surface, in causing folds in the crust from beneath which it was derived. Problems of fundamental importance are outlined by the considerations under review.

To the immediate question, What is the best plan for enlarging our knowledge of the physiography of volcanoes? the reply seems pertinent: Press on with the study of both active and dormant or extinct examples. In this connection it should be remembered that, while the individual volcanoes and volcanic mountains which have been critically studied can be enumerated on the fingers of one's hands, those which are practically unknown number many thousands. The fact that Mont Pelé and La Soufrière of St. Vincent during their recent periods of activity furnished examples of at least two important phases of volcanic eruptions not previously recognized is an assurance of rich returns when other eruptions are critically investigated.

While it is difficult to formulate the precise questions so numerous

are they, to be asked of volcanoes, whether active, dormant, or dead, and in various stages of decay and dissolution, it is plain that all the facts that can be learned concerning them should be classified and put on record, and their more obvious bearings on the fundamental questions concerning the condition of the earth's interior, and the changes there taking place, pointed out. In this connection—and as is true in all branches of research—the fact may be recalled that energy expended in discovering, classifying, and recording facts decreases the time and force necessary for the framing of multiple hypotheses. With an abundance of well-classified and pertinent observations in hand, the nature of the thread on which the gems of truth should be strung usually declares itself.

Résumé.—On a previous page of this essay the desirability was suggested of recognizing ideal types with the aid of which the multitudinous surface features of the earth could be classified and studied. Thus far we have considered the elements in the relief of the earth's surface which have resulted from changes within its mass. We term them primary physiographic features, because their birth precedes the modifications of the lithosphere due to agencies acting externally. They are (1) the topographic forms resulting from contraction on account of cooling, or of condensation owing to growth in mass; (2) the surface changes produced by intrusions of magmas into the earth's outer shell; and (3) the results of volcanic eruption. Among the more important idealized models in our future physiographic museum there should be displayed continental platforms, oceanic basins, corrugated mountains, block mountains, domes of various and some of vast dimensions upraised by intrusions, volcanic cones, lava plateaus, etc. These are the major physiographic types, or the larger monoliths from which the rock-hewn temples of the earth have been sculptured by forces acting on the surface of the lithosphere and deriving their energy mainly from the sun. Resulting from surface changes come a vast array of both constructive and destructive physiographic features, which may consistently be termed secondary. Under secondary features may be included also relational topographic forms, such as islands in water, in glaciers, and in lava fields. In the study of the primary features of the earth's surface the work of the physiographer is most intimately linked with that of the geolo-

gist, but, on passing to the secondary feature, the influence of life becomes apparent, and the relation of man to nature is in the end the leading theme.

SECONDARY PHYSIOGRAPHIC FEATURES.

The most familiar features of land areas, as is well known, are those which owe their existence to the work of moving agencies resident on the earth's surface, such as the wind, streams, glaciers, waves, currents, etc. The forces at work are set in motion by energy derived from without the earth, and the material worked upon is brought within the range of their activities by forces resident within the earth which cause deformations of, or additions to, its surface. The earth-born primary physiographic features are thus modified by sun-derived forces, and a vast array of secondary modifications of relief are produced which give variety and beauty, particularly to those portions of the lithosphere which are exposed for a time to the air. The study of secondary physiographic features has produced a rich and abundant harvest, especially during the last quarter of a century, and the returns are still coming in with seemingly an accelerated rate.

The themes for study are here mainly the various processes of erosion and deposition of the material forming the outer film of the lithosphere, and the characteristics of the destructive and constructive topographic forms produced. With the knowledge gained concerning the changes now in progress on the ocean's shore, in the forest, by the river side, on the snow-clad and glacier-covered mountains, etc., the physiographer seeks to decipher the records made in similar situations during the past. Two groups of problems are in sight in this connection; one is concerned with observing, classifying, and recording the changes now in progress; and the other has for its chief aim the translation, in terms of the agencies now at work, of the records left by past changes. We find that today the same area is being inscribed perhaps in several different ways. The surface of the earth, like an ancient manuscript, is frequently written upon in different directions, and with different characters. It is the duty of the physiographer to translate this ancient palimpsest, and deduce from it the history of the development of the features of the earth's surface. It has

been said that "geology is the geography of the past," but to the physiographer this formula has a yet deeper meaning. There is a physiography of the past, of venerable antiquity, which has begun to receive attention. Ancient land surfaces, buried during geological eras beneath terranes which were deposited upon them, have here and there been exposed once more to the light of the sun, owing to the removal by erosion of their protecting coverings. In northern Michigan, for example, one may gaze on the veritable hills and valleys which were fashioned by the wind, rain, and streams of pre-Potsdam days of sunshine and shower. These *fossil landscapes* invite special study, not only on account of their poetic suggestiveness, but as furnishing evidence, supplementary to that afforded by organic records, ripple marks, shrinkage cracks, etc., as to the oneness of nature's processes throughout eons of time. The consideration of past physiographic conditions, the tracing of former geographic cycles, the study of the concurrent development of primary and secondary physiographic features, the causes and effects of past climatic changes, and the influences of these and still other events of former ages on the present expression of the face of nature, offer not only a fascinating, but a far extended field for research.

One especially important development of the study of past physiographic conditions, and the manner in which they merge with the present phase of the same history, is the connection between the life of the earth and its control by physical environment. The present and past distribution of floras and faunas affords important data supplementary to those recorded by abandoned stream channels, glacier scorings, elevated and depressed shore lines, desiccated lake basins, and other physical evidences of former geographic changes.

In the excursions into the domain of the unknown, here suggested, the physiographer seeks the companionship and counsel of both the geologist and the biologist.

PHYSIOGRAPHY AND LIFE.

In the study of the relation between physiography and the present state of development of living organisms on the earth, it is convenient and logical to recognize two great subdivisions: the one, the control exerted by physiographic features on the distribution of plants and

animals; and the other, the reaction of life on its physical environment, and the modification in the relief of the lithosphere and the geography of its surface thus produced. Although man is embraced in each of these categories, there are sufficient reasons for considering his relations to his environment separately from those of the lower forms of life.

The dependence of life on its physical environment has received much attention from botanists and zoölogists, and is perhaps the leading thesis now claiming their attention. So important is this branch of study that a name "ecology," has been coined by which to designate it. The phase of nature-study thus made prominent pertains to the marvelously delicate adjustment that has been found to exist between the distribution of life and the nature of the region it inhabits. Among the interesting themes involved are topographic relief, degree of comminution and disintegration of the surface blanket of rock waste, depth and freedom of penetration of water and air into the life-sustaining film of the earth's surface, and the concurrent changes in life with variations in these and other physical conditions. In this most fascinating branch of study the ecologist borrows freely of the physiographer, and makes payment in peat bogs, living vegetable dams in streams, organic acids serviceable for rock disintegration and decay, deposits of calcium carbonate and silica in lakes and about springs, vast incipient coal beds in the tundras of the far north, and numerous other ways.

From the physiographic point of view, however, the many and intricate ways in which life leads to modifications in the features of the lithosphere are of more direct interest than studies in ecology. Much has been accomplished in this direction, but it is evident that as yet but partially explored paths leading through the borderland between biology and physiography remain to be critically examined.

In connection with the changes in progress on the earth's surface, due to the influence of organic agencies, and the application of that knowledge in interpreting past changes, the study of the influences exerted by the lowest forms of life in both the botanical and the zoölogical scale seems most promising to the physiographer.

The secretion of calcium carbonate and silica by one-celled organisms, as is well known, has led to the accumulation of vast

deposits like the oozes on the sea-floor, beds of diatomaceous earth, deposits about hot springs, the so-called marl of fresh-water lakes, etc. A review of the several ways in which such accumulations are formed, and an extension of the search in various directions, give promise that other and equally wonderful results flowing from the activities of the lowest form of life would be discovered. The mode of deposition of iron, and perhaps of manganese, the generation of hydrocarbons, the origin of extensive sheets of seemingly non-fossiliferous limestone and dolomite, the method by which the beautiful onyx marbles are laid down, film on film, the nature of the chert so abundant in many terranes and so conspicuous in the surface waste of extensive regions, and other equally important deposits which exert a profound and frequently controlling influence on topographic forms, seemingly demand study with the hypothesis in mind that they owe their origin to the vital action of low forms of plants or animals. Not only the concentration of mineral matter by one-celled organisms, but the part played by similar organisms in the comprehensive processes of denudation, also invites renewed attention. Many of the organisms in question do not secrete hard parts, and hence are incapable of directly aiding in the concentration of inorganic solids on the surface of the lithosphere. If not assisting in the building of physiographic structures, the suspicion is warrantable that they are engaged in sapping their foundations. The wide distribution of one-celled organisms—and indeed, as one may say, their omnipresence on the earth's surface—and their seeming independence, as a class, to differences in temperature, light, and humidity, enable them to exert an unseen and silent influence, not suspected until some cumulative and conspicuous result is reached. The importance of bacteria in promoting decay, and in consequence the formation of acids which take a leading part in the solution and redeposition of mineral substances, the rôle played by certain legions of the invisible hosts in secreting nitrogen from the air and thus aiding vegetable growth and perhaps to be held accountable also for the concentration of nitrates in cavern earths, the part others play in fermentation, and the diseases produced in plants and animals by both bacteria and protozoa, render it evident that an energy of primary importance to the physiographer is furnished by these the lowest of living forms.

Physiographers were given a new point of view when Darwin explained the part played by the humble earthworms in modifying the earth's surface. As it seems, still other advances in our knowledge of the changes in progress in the vast laboratory in which we live may be gained by studying the ways in which organisms far lower in the scale than the earthworm are supplying material for the building of mountains or assisting in the leveling of plains.

In brief, a review of the inter-relations of physiography and life, shows that from the lofty snow-fields reddened by *Protoccocus*, to the bottom of the ocean, the surface of the lithosphere is nearly everywhere enveloped in a film teeming with life. In part the vital forces at work are reconcentrating material and adding to the solid framework of the globe, and in part, but less obviously, aiding in rock decay and disintegration. Throughout this vast complex cycle of changes new physiographic features are appearing, others disappearing, and one and all, to a greater or less degree, are undergoing modifications. The wide extent of the changes in progress, and their known importance in certain instances, are justification for the belief that the physiographer as well as the ecologist will find many problems of fundamental importance to his science in the inter-relations of life and physiographic conditions.

PHYSIOGRAPHY AND MAN.

Go forth, subdue and replenish the earth, is the language of Scripture. The observed results show that, while man strives to bend nature to his will, he himself is a plastic organism that is molded by the many and complex external forces with which it comes in contact. Here again two groups of themes present themselves to the physiographer: one, embracing the influences of environment on man; and the other, the changes in the features of the earth's surface, brought about by human agencies. In the first the physiographer can aid the anthropologist, the historian, the socialist, etc.; and in the second, which is more definitely a part of his own specialty, he searches for suggestive facts throughout the entire domain of human activities. It is in these two directions that the student of the earth's surface finds the most difficult and the most instructive of the problems in which he takes delight, and the richest rewards for his efforts.

The control exerted by physiographical environment on human development is so subtle, so concealed beneath seemingly accidental circumstances, and its importance so obscured by psychological conditions, that its recognition has been of slow growth. The countless adjustments of both the individual man and of groups of men in communities, nations, and races to physical conditions, is so familiar that the sequence of causes leading to observed results passes as a matter of course and to a great extent fails to excite comment. The due recognition of the influence of physiographic environment on history is now coming to the front, and, as is evident, the rewriting of history, and especially the history of industry, from the point of view of the physiographer, is one of the great tasks of the future. The problems in this broad field are countless, and the end in view is similar to those embraced in dynamical physiography, namely, the study of the various ways in which man is now influenced by his physical environment, with the view of interpreting the records of similar changes in the past and of predicting future results. Or more definitely formulated: peoples have reached a high degree of culture under certain multiple conditions of environment, while other peoples, exposed to other combinations of conditions, have remained stationary, or retrograded and become degenerate. What are the essential conditions in control in the one case or the other? Can predictions be made as to what the results of a given combination of physical conditions on a given community will be, in spite of that other and still more mobile, and as yet but little understood, group of conditions embraced under the term *psychology?* Many profound questions, in the solution of which the physiographer unites his efforts with those of the student of the humanities, present themselves for study during the century that is yet young.

Within the broader questions just suggested are many others that are more concrete and definite, and of vital importance to mankind, which can be conveniently grouped under the term *economic physiography*. The problems which here present themselves share their chief interests with the engineer. They relate to plans for transportation in all of its various forms, drainage, irrigation, water supply, sanitation, choice of municipal locations, control of river floods, selection of cities for homes, farms, vineyards, factories, etc. In

every branch of industry a critical knowledge of the physical conditions, both favorable and adverse to the economic ends in view, and of the limitations of the daily, seasonal, and secular changes they experience, is of primary commercial importance. Although the money value of truth should be a secondary consideration to the truth-seekers, a critical study of the influence of environment on industry is as truly a matter of scientific research as any of the less complex and less directly utilitarian branches of physiography.

The reaction of human activities on physiographic features presents two great groups of problems. These embrace, on the one hand, the far-reaching and frequently cumulative effects of man's interference with the delicate adjustment reached in natural conditions before his influence became manifest; and, on the other hand, the effects of such changes on man's welfare.

A change amounting to but little less than a revolution in the long-established processes by which the features of the earth's surface are modified and developed, accompanied the advancement of man from a state of barbarism to one of civilization, and is most strikingly illustrated when men skilled in the arts migrate to a previously unoccupied region. This new factor in the earth's history demands conspicuous changes in the methods of study usually employed by physiographers, and makes prominent a series of investigations the full significance of which is as yet obscure. The wholesale destruction of forests, drainage of marshes, diversion of streams, building of restraining levees along river banks, tillage of land, abandonment of regions once under cultivation, the introduction of domestic animals in large numbers into arid regions and the consequent modification, and frequently the destruction, of the natural vegetal covering of the soil, and many other sweeping changes incident to man's industrial development, are fraught with consequences most significant to the student of nature, and of profound import to the future of the human race. From the point of view of the physiographer, the ultimate result of these great changes in the surface conditions of the earth can to a great extent be expressed in one word, and that word is *desolation*. In view of the suicidal lack of forethought manifest in the activities of peoples and, as experience shows, increasing in many directions in destructiveness with industrial prog-

ress, the problems that confront the physiographer are not only what far-reaching changes in the surface condition of the land result therefrom, but how the ruin wrought can be repaired, and how human advancement can be continued and its deleterious consequences on the fundamental conditions to which it owes its birth and development be avoided or lessened. Considerations which lessen the horrors of the regions crossed by industrial armies are that nature, no matter how severely torn, has great recuperative power and tends to heal her wounds; and also that man, through the science of agriculture particularly, although greatly modifying natural conditions, is able to reconstruct his environment and, so long as intelligent care is exercised, adjust it to his peculiar needs. In the relations of physiography to man, as the above hasty sketch is intended to show, the themes for research are many and important. As a suggestive summary, they include the review of history with the aid that modernized physical geography furnishes; the recognition of a strong undercurrent due to inorganic conditions in the political, social, and industrial development of peoples; the incorporation of physiographic laws into the formulas used by the engineer in all of his far-reaching plans; the calling of a halt in the wanton destruction of the beauties of nature, and the providing of a check on the greed of man which casts a baneful shadow on future generations. Great as are the results to be expected from a better knowledge of the mode of origin of the earth, its deformation by internal changes, and the removal and redeposition of material by forces resident on its surface, the combined results of all these studies culminate in the relation of man to his environment.

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WIDESPREAD OCCURRENCE OF FAYALITE IN CERTAIN IGNEOUS ROCKS OF CENTRAL WISCONSIN.

In central Wisconsin, in the vicinity of Wausau, forming the southern portion of the pre-Cambrian district of the northern half of the state, is a wide variety of intrusive igneous rocks. Chief among these intrusives, which constitute perhaps 75 per cent. of the rock formations for many miles around Wausau, is a complex series of holocrystalline rocks ranging from granite, high in silica, to quartz syenite, nepheline, and sodalite syenites, and related basic, alkali-rich rocks. Associated with this series are an older series of basic rocks and a still older flow of rhyolite, to both of which the various members of the granite-syenite series bear the same structural relations.

The habitat of the fayalite is in certain phases of the granite-syenite series, and it is not known to be in the other varieties of igneous rock of the region. The mineral fayalite, it will be recalled, is the pure iron olivine, iron chrysolite, having the formula $2FeO, SiO_2$, and the theoretical composition, ferrous oxide 70.6, and silica 29.4 per cent. Considered in its entirety, the series in which the fayalite occurs resembles in many respects, though not in all, other well-known series of nepheline-bearing and related alkali-rich rocks, such as those in Arkansas, in the Christiania region of southern Norway, and in Essex County, Mass.

The composition of some of the phases of the central Wisconsin alkali-rich rocks is shown in the subjoined table. The analyses were made by Professor W. W. Daniells, professor of chemistry in the University of Wisconsin.

In the analyses attention is called to the fairly regular increase in amount of alumina and the alkalies as the silica decreases. The iron is abundant and is fairly uniform in amount, with the exception of that in the granite rich in quartz. With respect to the lime and magnesia, these constituents, like the iron, do not differ appreciably in the various phases. Attention is especially called to the uniformly low content of magnesia, which is without doubt one of the causes of the development of the ferrous silicate, fayalite, in the magma.

	I	II	III.	IV	V	VI
SiO_2	76.54	67.99	61.18	57.48	54.79	54.76
Al_2O_3	13.82	15.85	19.72	20.04	22.87	24.72
Fe_2O_3	1.62	5.36	3.71	5.64	1.74	2.73
FeO	....		1.32	3.76	3.24	2.35
MnO	....	....	....	....	trace	....
MgO	0.01	0.41	trace	0.40	1.92	0.10
CaO	0.85	1.78	2.64	1.70	trace	1.67
Na_2O	4.32	3.21	5.28	7.25	10.75	10.38
K_2O	2.31	4.81	5.66	3.65	4.06	2.37
H_2O	0.20	0.30	0.32	0.25	.....	0.55
Cl	....	....	....	....	0.54	....
F	....	....	....	....	0.08	....
ZrO_2	....	....	....	....	0.07	....
Total	99.67	99.71	99.83	100.17	99.75	99.63

I. Granite. Quarry granite known as the Wausau red granite. Consists mainly of albite, orthoclase, and quartz.

II. Amphibole granite (5298).[1] Consists mainly of microperthite, quartz, and an amphibole rich in ferric oxide, and alumina.

III. Hedenbergite-quartz syenite (5917). Consists mainly of microperthite, quartz, hedenbergite, arfvedsonite, lepidomelane, and fayalite.

IV. Amphibole syenite (6011). Consists mainly of orthoclase and bluish-green amphibole, and some magnetite, mica, fluorite, and zircon.

V. Sodalite-nepheline syenite (6426). Consists mainly of anorthoclase, nepheline, sodalite, and hedenbergite, with some fluorite.

VI. Nepheline syenite (5829). Consists mainly of nepheline, orthoclase, hedenbergite, and some fayalite.

It should be understood that not all the phases of rock represented in this alkali-rich series is indicated in the above table. Nor is the range in content of silica supposed to be outlined. Ægirite is a common constituent of many of the rocks, but analyses of the ægirite-bearing phases have not been made. Those who have studied the alkali-rich magmas can best appreciate the amount of work necessary, and the complexity of the problem met with, in describing these interesting rocks from the mineralogical standpoint. Some of the prevailing amphiboles, pyroxenes, and micas, as well as other minerals, have been separated from the rocks and analyzed, and hence where varietal names are used such use is based upon knowledge of the chemical composition. The object of the present paper is merely to describe the general character, occurrence, and signification of

[1] The numbers refer to specimens in the Wisconsin Survey collection.

the fayalite found in various phases of the series, rather than a complete description of these rocks as a whole.

The nature of the chemical and mineral composition of the series will be briefly referred to again. In the meantime it may be of interest to show how the true character of the fayalite was determined. Under the microscope it appears in ordinary light as a honey-yellow mineral, and under crossed nicols it has bright polarizing colors, resembling olivine. The minerals associated with it, however, such as an abundance of quartz, orthoclase, and albite, were not the ones usually found with olivine. The composition of the rock, with its very small amount of magnesia and the alteration product of the mineral wholly to iron oxide, free from serpentine, led to the idea that it might be fayalite.

A rough separation of the mineral was made by means of crushing the quartz syenite (like III) bearing considerable of the unknown mineral, and passing the finely crushed material through a Retgers solution of nitrate of thallium and nitrate of silver. A considerable amount of the heaviest material of the rock, which contained, besides the fayalite, some feldspar and pyroxene, was analyzed to see if any appreciable amount of magnesia was present, and to see if the theory that the yellow mineral was fayalite was probably correct.

The material was analyzed by Dr. Victor Lehner, and is seen to have been largely iron and silica, and almost entirely free from magnesia, as follows:

SiO_2	32 10%
Al_2O_3	3.54
Fe_2O_3	19.86
FeO	37.56
MgO	0.07
CaO	0.57
P_2O_5	none
MnO	trace
TiO_2	none
Undetermined	6.30
	100.00

After this rough test, a careful separation of the yellow mineral was made. With the Retgers solution the heavy minerals of the crushed rock were separated. It was impossible to separate with

the Retger's solution the fayalite from the iron oxide, as the two were so intimately mixed by alteration and intergrowth. The iron oxide, which was strongly magnetic, was very largely removed by means of a magnet, and finally sorting out the honey-yellow fayalite from the magnetic iron oxide by hand had to be resorted to. After considerable work, 0.3610 grams of the nearly pure fayalite was separated, which was analyzed by Dr. Victor Lehner, and found to be as follows:

SiO_2	33.77%
Fe_2O_3	0.23
FeO	62.09
Undetermined	3.91
	100.00

The materials associated with the fayalite, and necessarily included in the analysis, were small particles of feldspar, quartz, pyroxene, and amphibole. The undetermined portion in this second analysis, 3.91 per cent., as indicated by comparison with the first rough analysis, is very probably mainly alumina and the alkalies which may be assumed to be combined with perhaps 4 or 5 per cent. of silica to form the associated silicate minerals. An additional source of silica, probably 1 or 2 per cent., was due to small included fragments of quartz. After deducting, therefore, an amount of silica—6 or 7 per cent.—present in mineral other than fayalite, it will be seen that the ferrous oxide and silica occur in approximately the proportions found in fayalite.

Under the microscope the fayalite has the appearance of this mineral as usually described. In ordinary light it has a light stone color, with yellowish-green or honey-yellow tints. It is distinctly pleochroic, the green tinge changing from a light to a darker shade. The double refraction is strong, probably stronger than for olivine. It apparently has two fairly well-defined planes of cleavage, as illustrated in Fig. 1, which are probably parallel to the pinnacoids, 001, and 010.

The fayalite occurs in the quartz-syenite, having a silica content of 61.18 per cent., and to a very small extent in the amphibole granite, bearing 67.99 per cent. silica. In phases of the quartz syenite it probably constitutes from 1 to 5 per cent. of the rock, and was noted

in many thin sections of this variety from widely different parts of the district. In the rocks bearing quartz it is associated with the feldspars, orthoclase, albite, and microperthite; with the calcium-iron-amphibole, arfvedsonite; with the calcium-iron-pyroxene, hedenbergite; and with iron mica containing large amounts of potassium. In phases of the non-quartzose and nepheline-bearing rocks of the series the fayalite also contributes a fraction of 1 per cent. to as much as 5 per cent. of the rock. In some of the nepheline-rich rocks the fayalite is the only dark-colored mineral noted in the thin sections. In these rocks the fayalite occurs with orthoclase and microperthite, nepheline, sodalite, the soda amphiboles of the riebeckite, and crocidolite type, and the calcium-iron pyroxene, hedenbergite, and the potash-iron mica lepidomelane.

Fig. 1.—Photomicrograph of fayalite in nepheline syenite; ×60. The fayalite, light-colored, is surrounded on nearly all sides by a black border of magnetic iron oxide. Portions of it are in contact with feldspar and hedenbergite. The greatest length of the fayalite in this section is along the *c* axis, parallel to which is indistinct parting or cleavage. The areas within the fayalite are colored dark by photography, and in reality are yellowish-brown and bluish mineral inclusions. The yellowish-brown inclusions are in irregular areas, and are probably yellowish hydroxide of iron, göthite, formed by alteration of the fayalite. The bluish inclusions are finely striated crystals of a bluish amphibole.

The various rocks in which the fayalite occurs is thus seen to have a considerable range in certain chemical constituents, such as silica, alumina, and the alkalies, and also in mineral composition. The area over which these rocks are distributed is quite extensive. The amphibole granite and quartz syenite cover several hundred square miles, and the nepheline-bearing and related basic rocks, from fifteen to twenty square miles.

The fayalite, in the various phases of rock in which it occurs, has the associations and relations of a normal, original constituent of

the rock. It does not occur in veins, segregations, or cavities, but as a common constituent distributed through the rock, like the quartz, feldspar, nepheline, and other common rock-forming minerals with which it is associated.

Like the other abundant minerals associated with it, it does not occur in idiomorphic crystals, but assumes shapes in its development due to the mutual interference of surrounding minerals. Where present with an abundance of dark-colored silicates, it is usually in direct contact with them, but in quartz syenite it occurs in direct contact with quartz, and in certain phases of the nepheline syenite it is entirely surrounded by nepheline, or nepheline and feldspar.

The fayalite has not been observed to occcur with the alkali-iron pyroxene, ægirite, which is a common constituent of several phases of the nepheline-bearing rocks. While it may be stated with certainty that these two iron-rich minerals do not occur in the same thin sections of rock examined—and this includes a considerable number—with this special relation in mind, yet a final conclusion upon this point, it is believed, should be held in abeyance.

The pyroxene, ægirite, it will be recalled, contains a high percentage of ferric oxide and but a small proportion of ferrous oxide. On the other hand, the fayalite contains ferrous oxide only, and the pyroxenes, amphiboles, and micas abundantly associated with the fayalite, as shown by the analyses, contain a marked excess of ferrous oxide over ferric oxide.

It may be, therefore, that in those magmas, or portions of magmas, very poor in magnesia, which contain a large excess of ferrous oxide over ferric oxide, the chemical conditions for the development of fayalite exists, and in those containing an abundance of ferric oxide the conditions for the development of ægirite are present and that necessarily these two minerals will not be expressed in the same phase of rock. A deficiency of oxygen as well as of magnesia may therefore be necessary for the development of fayalite.

Fluorite is a persistent, though not an abundant, constituent of the various phases of this series. The fluorite is colorless, has low birefringence and perfect octahedral cleavage, and on account of its extremely low index of refraction, produces the apparent anomalous appearance of having a very high index of refraction. The

occurrence of fluorite in the various members of this series is but another expression, in addition to that of the prevalence of the fayalite, of the probable common magmatic source of the various phases of rocks here referred to as belonging to the same series.

The idea has prevailed, to some extent at least, that fayalite, on account of its extremely basic character and its association with quartz in certain rocks, and with spherulites and lithophysae, probably had only an aqueo-igneous origin in rocks rather than ordinary igneous origin. In this connection it may be well to call attention to the various occurrences of fayalite previously noted.

It has often been observed in crystalline slags. The first natural occurrence of fayalite observed[1] was in 1839 in nodules in volcanic rocks on the island of Fayal (whence the name is derived), one of the islands of the Azores. In the Mourne Mountains of Ireland it occurs,[2] filling drusy cavities in granite. Professor J. P. Iddings,[3] has described its occurrence with tridymite in spherulites and lithophysae in the obsidian of Obsidian Cliff, Yellowstone National Park; and Iddings and Penfield[4] have described its occurrence in the recent obsidian flows of the Lipari Islands. It also occurs in large crystals, apparently in "vugs," in a soda granite at Cheyenne Mountain, Colorado,[5] and in a pegmatite dike in hornblende granite at Rockport, Mass.[6] In the latter place, as described by Penfield and Forbes, it occurs as a lenticular shell of varying thickness, twelve to sixteen inches in diameter, filled on the inside with loose earthy material and enveloped by a layer of magnetite one inch thick. It is a fact worthy of note that this Rockport granite is a phase of the alkali-rich rock of Essex County.[7]

It is also found in cavities in the lava of Vesuvius erupted in 1631,

[1] *Poggendorf's Annalen*, Vol. LI, p. 160.

[2] DELESSE, *Bulletins de la Société géologique de France*, Vol. X (1853), p. 571.

[3] J. P. IDDINGS, *Seventh Annual Report*, U. S. Geological Survey (1885), pp. 270, 279.

[4] J. P. IDDINGS AND S. L. PENFIELD, *American Journal of Science*, Vol. XL (1890), p. 75.

[5] W. E. HIDDEN AND J. B. MACINTOSH, *ibid.*, Vol. XLI (1891), p. 439, and Vol. XXIX (1885), p. 250.

[6] S. L. PENFIELD AND E. H. FORBES, *ibid.*, Vol. LI (1890), p. 129.

[7] H. S. WASHINGTON, JOURNAL OF GEOLOGY, Vol. VII (1899), p. 466.

occurring with sodalite and orthoclase. Lacroix has also noted the occurrence of fayalite in the trachyte lava of Mont Doré. In all these instances, with the possible exception of the last mentioned, it will be noted that the fayalite occurs either in cavities, veins, or segregations, and on this account it has been thought that it must necessarily be a product of aqueo-igneous origin.

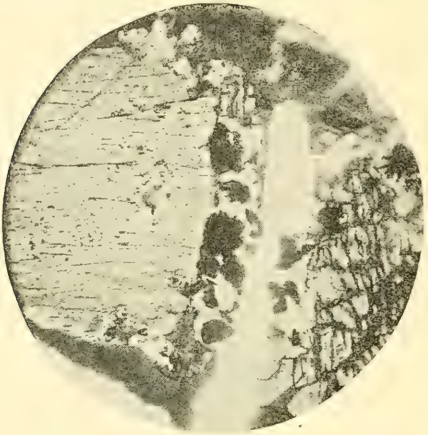

FIG. 2.—Photomicrograph of quartz-syenite; ×60. The crystals shown are fayalite, much fractured, on the right, hedenbergite on the left, both surrounded in part by bluish-green arfvedsonite. The black mineral is magnetite, and the colorless crystal is apatite.

It may be well, therefore, again to call attention to, and emphasize, the fact that not only does the fayalite occur as a persistent, and in places a fairly abundant, constituent of these various rocks described from central Wisconsin, but that it occurs here as a rock constituent under perfectly normal conditions.

The presence of fayalite as an essential constituent of a number of phases of this series would seem to indicate that, mineralogically and chemically, these phases are unique. And not only are the fayalite-bearing phases unusual, but also the other phases of the series, since they contain no magnesia-bearing minerals, and contain, besides the quartz, feldspar, and feldspathoids, only calcic-iron alumino silicates or alkali-iron alumino silicates, or combinations of them. It is a well-known fact, of course, that all the alkali-rich rocks, such as those associated with nepheline-bearing rocks, contain much less magnesia than lime, and that not only is the proportion of magnesia to lime in these alkali rocks small as compared with the proportion in the usual basic rocks, but that it is also much smaller than occurs in average igneous rocks.

In comparison with other somewhat similar and well-known alkali-rich rocks, such as the nepheline-bearing and associated rocks of the Christiania region of southern Norway, described by Brögger,°

° W. C. BRÖGGER, *Zeitschrift für Krystallographie und Mineralogie*, Vol. XVI (1890).

it may be stated that the latter differ radically from the alkali rocks of Wisconsin in their much higher content of magnesia. In Brögger's series there is, on the average, five or six times as much magnesia as in these, otherwise similar, Wisconsin rocks. The nepheline syenites and quartz syenites of Arkansas, described by J. Francis Williams,[1] are more like these Wisconsin rocks, but the Arkansas rocks, otherwise similar, have much more magnesia than those here described. The nepheline-bearing and associated rocks of Essex County,[2] Mass., are generally comparatively high in magnesia and are closely related to gabbro and diorite.

When the mineralogical composition of these various alkali rocks, from different parts of the world, is compared, a much more striking dissimilarity is to be noted. The difference, of course, does not lie in the nature of the quartz, feldspar, nepheline, and sodalite, but with the dark-colored silicates; and since the former constitute much the larger portion of the rock, the difference is necessarily accentuated in the less abundant iron silicates. In these Wisconsin rocks, therefore, the low content of magnesia finds expression in the development of fayalite, and of pyroxenes, amphiboles, and micas comparatively low or free from magnesia. Whether or not fayalite or other magnesia-free silicate develops in the magma probably depends also, as already stated, upon the oxide condition of the iron. A deficiency of oxygen in the magma, as well as of magnesia, therefore, may be the controlling factors in the development of fayalite; and in those portions of the magma where oxygen was more abundant the more complex ferric-oxide-bearing silicates, such as ægirite, were formed.

In comparison with other somewhat similar, alkali-rich rock series, such as the syenite of southern Norway, Arkansas, and Essex County, Mass., it may be stated that fayalite has not been observed in any of them. Furthermore, the pyroxenes present in these rocks are generally the magnesia-rich varieties, such as augite or diopside, which tend to grade to ægirite through augite-ægirite and diopside-ægirite.

The alteration of the fayalite in some instances is quite extensive, the process of alteration consisting merely in the breaking up of this

[1] J. F. Williams, *Arkansas Geological Survey*, Vol. II (1891).

[2] H. S. Washington, Journal of Geology, Vol. VII (1899), p. 463.

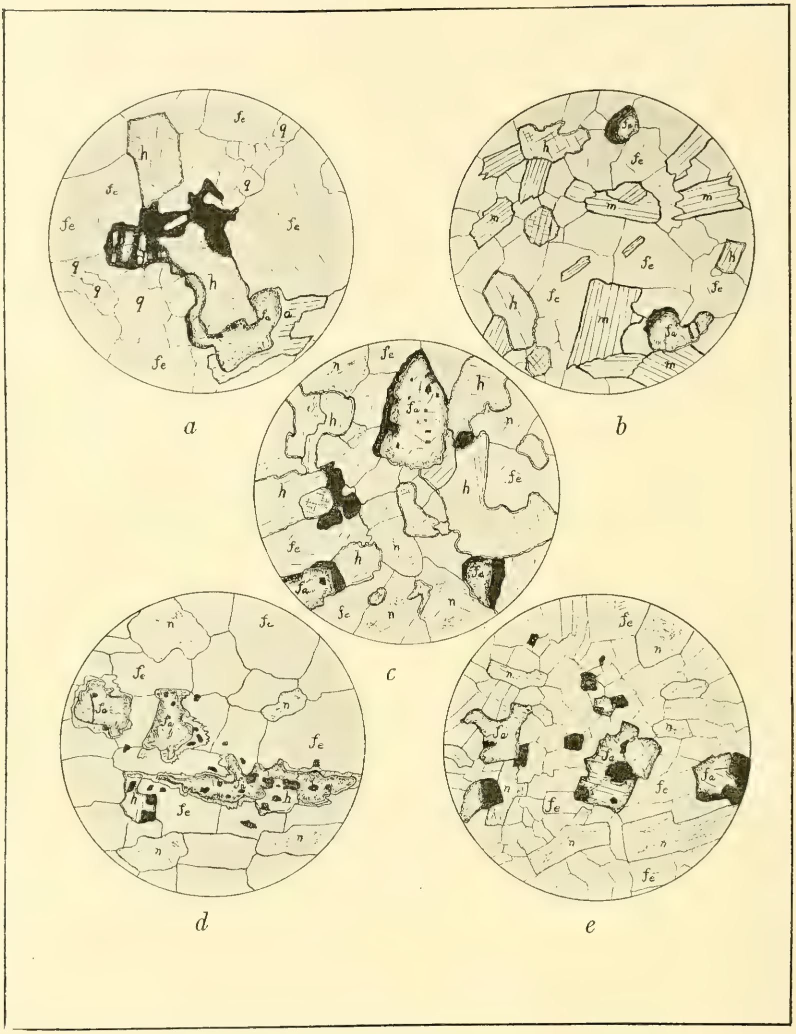

FIG. 3.—*a*. Hedenbergite-quartz-syenite (6639); ×20. The minerals shown are: alkali-feldspar (*fe*), quartz (*q*), fayalite (*fa*), hedenbergite (*h*), arfvedsonite (*a*), and magnetite, the black mineral. There is also present a small amount of fluorite and apatite.

b. Hedenbergite-mica-syenite (6597); ×20. The minerals shown are: alkali-feldspar (*fe*), brown mica (*m*), hedenbergite (*h*), fayalite (*fa*), and magnetite. A small amount of fluorite and apatite is also present.

c. Hedenbergite-nepheline-syenite (6600); ×20. The minerals shown are: alkali-feldspar (*fe*), nepheline (*n*), hedenbergite (*h*), fayalite (*fa*), and magnetite.

d. Fayalite-nepheline-syenite (5275); ×20. The minerals shown are: alkali-feldspar (*fe*), nepheline (*n*), hedenbergite (*h*), fayalite (*fa*), and magnetite.

e. Fayalite-nepheline-syenite (5275); ×20. The minerals shown are: alkali-feldspar (*fe*), nepheline (*n*), fayalite (*fa*), and magnetite.

ferrous silicate mineral into the oxide of iron and oxide of silica, the silica being carried away in solution, probably as hydroxide of silica, and the oxide of iron, which is apparently always magnetic, left as residual material. Quartz as an undoubted residual product of the alteration was not observed in any case. The alteration of the fayalite to magnetite, as indicated in the photomicrograph, takes place about the borders of the crystals, and along the fractures and cleavage.

Not all the iron oxide associated with the fayalite, however, is of secondary origin. There can be little doubt that some of the iron oxide occurring as rims surrounding the fayalite, as well as that occurring as inclusions within the fayalite, is of primary origin. The distribution of the iron oxide, probably mainly magnetite, is such as to indicate that most of it occurring in the rocks is an original separation from the magma, for it is by no means entirely confined to the vicinity of the fayalite, or of the other dark-colored constituents, but often appears to be entirely independent of them. (See Figs. 1–3.) Rims of hedenbergite also surround the fayalite (Fig. 3, *d*), and sometimes the reverse is true and fayalite and iron oxide nearly completely surround hedenbergite (Fig. 3, *a*). Furthermore, these associations are just as abundant in perfectly fresh rocks, as illustrated in phases from a well taken fifty or sixty feet from the surface, as in specimens collected from the rapids of the Wisconsin River at Wausau, and elsewhere, immediately beneath the soil.

While much of the fayalite appeared to show more or less alteration, still in most cases the alteration was never complete, at least in crystals of the ordinary, or average, size, even when the fayalite-bearing rock was immediately associated with the soil, or running water. Attention has already been called to the alteration of the large nodules of fayalite in pegmatite, sixty feet below the surface, at Rockport, Mass., where the magnetite was observed as forming a shell about the fayalite. In all other cases noted in literature, the alteration of fayalite has been quite generally observed as being to magnetic material, and in this regard it is quite similar to the alteration of olivine, in which case the secondary products are usually serpentine and magnetite.

Samuel Weidman.

Madison, Wis.

REVIEWS.

The Clays and Clay Industry of New Jersey. By HEINRICH RIES AND HENRY B. KÜMMEL, ASSISTED BY GEORGE N. KNAPP. (Geological Survey of New Jersey, Vol. VI.) Pp. xxi + 548; LVI plates, and 41 figures in text.

IN 1868 the Geological Survey of New Jersey, Professor George H. Cook, state geologist, published a full report on the clays of the state—a report which was of great service in its day. Ten years later a further report on some of the more important clay districts of the state was issued. These earlier reports were long since exhausted. Furthermore, the development of the clay industry and the progress of knowledge of the geology of the state, have created a demand for the new report on the clays of the state. The present volume is in response to this demand, and brings the subject up to date.

The importance of the clay industry in New Jersey is shown by the fact that in 1902, the last year for which statistics are available, the total value of the clay products of the state was more than $12,600,000.

The economic phases of the subject are primarily the work of Dr. Ries, while the geological questions involved are primarily the work of Dr. Kümmel, who, however, has availed himself of the data in possession of Mr. Knapp, who became familiar with the Cretaceous and later strata of the state in connection with his work on the Pleistocene of southern New Jersey.

The volume is divided into four parts as follows: (1) Clay and its Properties, including a discussion of the occurrence of clay, the methods by which it is worked, as well as its physical and chemical properties (pp. 1–115); (2) Stratigraphy, the clay of the state being found in various formations, chiefly in the Cretaceous, Tertiary, and Pleistocene (pp. 119–203); (3) The Manufacture of Clay Wares, which include brick, fire-brick, terra cotta, wares for structural work, tile and pottery (pp. 205–342); (4) The Economic Geology of the New Jersey Clays pp. 343–508). To these four parts are added appendices giving statistics of clay production, bibliography of clay literature, and tables of chemical analyses and physical tests. This outline of the contents of the volume gives an adequate idea of its scope.

To the systematic geologist one of the chief points of interest in the volume lies in the classification of the Cretaceous formations. This is as follows:

III. The Marl series.
  5. Upper marl (in part).
  4. Limesand (including the Yellow sand).
  3. Middle (Sewell) marl.
  2. Red (Red Bank) sand.
  1. Lower (Navesink) marl.

II. Clay Marl series.
  5. Wenonah sand.
  4. Marshalltown clay-marl.
  3. Columbus sand.
  2. Woodbury clay.
  1. Merchantville clay.

I. The Raritan clay series.

This subdivision, it is to be noted, is different from that which has been used generally. It is adopted because, in addition to other reasons cited, it is "more accurate" than the classifications heretofore published. The subdivisions of the Clay-Marl series here given were made out by Mr. Knapp some eight or ten years ago. It is to be noted, further, that the difference between this classification and the one heretofore published[1] does not consist merely in the greater number of subdivisions of the several series. The lines of subdivision between the major divisions are not the same as in the earlier classification. Various specific errors in that classification are distinctly pointed out. It may be added that, as a result of recent work done by the State Survey, the subdivisions here proposed have been shown to hold paleontologically as well as stratigraphically, though the results of the recent paleontological studies have not been published.

The press work of the volume is excellent, and the Survey and the state are to be congratulated on the general excellence of the volume as to both substance and form.

J. H. L.

Oil and Gas. Levels. (Vol. IA, West Virginia Geological Survey.) Pp. xi+625. I. C. WHITE, State Geologist.

THE earlier volume (Vol. I) of this Survey on Oil and Gas of the State was exhausted some time since, and the present volume is its successor. In the new volume the general discussions of the previous volume

[1] W. B. CLARK, *Annual Report*, Geology of New Jersey, for 1897.

reappear, with some revision, and many new data, gathered since the publication of the earlier volume, are incorporated. The volume is thus brought up to date. Those who had reason to know the value of the first volume will welcome the revision.

The preface also announces a forthcoming volume, to be published probably in 1905, on the clays, limestones, and building-stones of West Virginia, to be prepared by Professor G. P. Grimsley.

R. D. S.

Baraboo Iron-Bearing District. (Bulletin XIII, Wisconsin Geological Survey.) By Samuel Weidman, Ph.D. Pp. x+190; 23 plates.

This volume gives an account of the geology of the region about Baraboo, dealing especially with the pre-Cambrian formations in which the iron ore occurs, and with the iron ore itself. This ore, it may be noted, has but recently been opened up.

The oldest rocks of the region are igneous, and include rhyolite, granite, and diorite. They appear in small isolated areas only. The sedimentary pre-Cambrian formations are three—namely, (1) the Baraboo quartzite, 3,000 to 5,000 feet thick, at the base; (2) the Seeley slate having a probable thickness of 500 feet or more; and (3) the Freedom formation (dolomite and iron-bearing), with a thickness of 400 or 500 feet. The iron ore is in the lower part of the Freedom formation. These formations are regarded as Middle or Upper Huronian. The author's statements on this point are (1) that the Baraboo series is probably the equivalent of the uppermost series of pre-Cambrian sediments in north central Wisconsin (p. 169); and (2) "if the Huronian system, instead of consisting of two series . . . . really consists of three unconformable sedimentary series . . . . then it seems to the writer that the Baraboo series is, with little doubt, either Middle Huronian or Upper Huronian, and more probably the former than the latter." Exact correlation of the iron-ore bed with the other iron-ore beds of the pre-Cambrian is not attempted.

The ore is associated with ferruginous slate, ferruginous chert, and ferruginous dolomite, and there are gradations from the ore to each of these rocks. The association of the ore with dolomite is believed to be unique among the pre-Cambrian iron districts of the United States. The ore is mainly red hematite, with a small amount of hydrated hematite. It is commonly "more like the hard phases of ore in the old ranges of the Lake Superior district than the soft hydrated ore of the Mesabi district. . . . . The ore is usually of Bessemer grade."

The ore has a bedded structure. The author believes it was originally a deposit of ferric hydrate or limonite formed in comparatively stagnant shallow water under conditions similar to those conditions existing where bog or lake ores are being formed today, and that through subsequent changes, long after the iron was deposited as limonite, while the formation was deeply buried below the surface and subjected to heat and pressure, the original limonite became to a large extent dehydrated and changed to hematite.

The extent of the ore is undetermined, but is in places 35 feet thick at right angles to the bedding.

One point in connection with the later formations of the region may be noted. The St. Peters sandstone is said to be unconformable on the Lower Magnesian limestone. This is also true in some other parts of the state, and perhaps generally, and gives point to the inquiry as to whether the Lower Magnesian limestone should not be classed with the Cambrian, rather than with the Ordovician, making the unconformity the plane of division between these two systems. This is the classification which was suggested by the Geological Survey of Wisconsin in 1881 (Vol. I).

R. D. S.

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THE

JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1904

THE PROFILE OF MATURITY IN ALPINE GLACIAL EROSION.[1]

THE literature of glaciation has not escaped the blemish of too free generalization. It was early asserted of the Sierra Nevada, for example, that Pleistocene glaciers of the alpine type, descending from an ice-cap in the summit region of the range, had reached to the range foot, and that the abnormally large canyons, particularly of the western flank, were the products, from head to foot, of glacial erosion. Such a statement made of southeastern Alaska, of the Scandinavian peninsula, or of the Patagonian Andes would not on the face of it be absurd. Nor was it absurd of the Sierra Nevada. It was possible, despite the low latitude, that ice-streams should have descended to the range foot, and it was theoretically not impossible that they should have excavated deep canyons. The matter, especially of glacier efficiency in erosion—a vexed question—is one mainly of the evidences. It cannot safely be handled deductively; and it need not be, since in glaciated mountains the evidences crowd the field. But the announcement was unscientific, because unsupported by facts of observation. Its author had no right to make it. On the other hand, it was no less unwarrantable and dogmatic to assert the contrary, which also was freely done.

My own acquaintance with the phenomena of glaciation of the alpine type had its beginning in the Sierra Nevada, in 1883, in the latitude of the Yosemite Valley—the so-called High Sierra. Prevailing opinion as to that region, it appeared, ranged between the

[1] Read at the International Congress of Arts and Science, St. Louis, September 21, 1904.

two extreme views indicated; namely that, as regards quantitative effects in degradation more especially, glaciation had been widely destructive of the preglacial topography, on the one hand; on the other, that it had been relatively protective. But there was no recognition of distinctive forms—beyond "U-canyons" and moraines. I had little notion, therefore, as to what I should discover; only an open mind and a lively curiosity.

I was a maker of topographic maps, of some experience, and had a topographer's familiarity with the erosion aspects of mountains; but only of unglaciated mountains I had as well, however, something of the inquisitiveness of the physiographer as to the origin and development of topographic forms.

The first station occupied in this work of survey was Mount Lyell, one of the most widely commanding summits of the vast mountainous tract of the High Sierra.

From Lyell there was disclosed a scheme of degradation for which I had not been in the least prepared. No accepted theory of erosion, glacial or other, explained either its ground-plan outlines or its canyon-valley profiles; and, so far as I can see, none makes intelligible its distinctive features now. The canyons, at their heads, were abnormally deep; they were broadly flat-bottomed rather than U-formed, the ratio of bottom width to depth often being several to one; and their head walls, as a rule, stood as nearly upright, apparently, as scaling of the rock would permit. I characterized them, figuratively, as "down at the heel." In many instances the basin floor, of naked, sound rock in large part, and showing a glistening polish on wet surfaces, was virtually without grade, its drainage an assemblage of shallow pools in disorderly connection; and not infrequently the grade was backward, a half-moon lake lying visibly deep against the curving talus of the head wall, and visibly shallowing forward upon the bare rock-floor.

The amphitheater bottom terminated forward in either a cross-cliff or a cascade stairway, descending, between high walls, to yet another flat. In this manner, in steps from flat to flat, commonly enough to be characteristic, the canyon made descent. In height, however, the initial cross-cliff at the head dominated all. The tread of the steps in the long stairway, as far as the eye could follow, greatly

lengthened in down-canyon order. In that order, also the phenomena of the faintly reversed grade and of the rock-basin lakes rapidly failed. Apparently, at the canyon head, the last touch of vanishing glaciation had been so recent that filling had not been initiated, while down-stream, incision of the step cliffs and aggradation of the flats had made at least a beginning in the immense task of grade adjustment; the tread of the step was graded forward, but so insensibly, as a rule, that its draining stream lingered in meanders on a strip of meadow, as though approaching base-level. These deep-sunk ribbon meadows, still thousands of feet above the sea and miles in length, reflecting in placid waters their bordering walls or abnormally steep slopes, presented an anomaly of the longitudinal profile in erosion no less impressive than that of the upright canyon heads.

In ground plan, the canyon heads crowded upon the summit upland, frequently intersecting. They scalloped its borders, producing remnantal-table effects. In plan as in profile, the inset arcs of the amphitheaters were vigorously suggestive of basal sapping and recession. The summit upland—the preglacial upland beyond a doubt—was recognizable only in patches, long and narrow and irregular in plan, detached and variously disposed as to orientation, but always in sharp tabular relief and always scalloped. I likened it then, and by way of illustration I can best do so now, to the irregular remnants of a sheet of dough, on the biscuit board, after the biscuit tin has done its work.

In large part, apparently, a preglacial summit topography had been channeled away. By sapping at low levels, by retrogressive undercutting on the part of individual ice-streams at their amphitheater heads in opposing disorderly ranks, the old surface had been consumed, leaving sinking ridges, meandering dulled divides, low cols or passes, and passageways of transection pointing to piracy and to wide shiftings of the glacial drainage. There was not wanting a scattering of the more evanescent sharp forms of transition which the hypothesis would require, as thin arêtes, small isolated table caps, needle-pointed Mätterhorn pyramids with incurving slopes, and subdued spires (in the massive granite tracts) with radiating spurs inclosing basin lakes. The broader areas of this deep erosion, where

complex channeling seemingly had passed into the phase of confluent glaciation, presented a much less intelligible ground-plan pattern. In every case, however, there was still an approximately central draining canyon. It was the sprawling high-walled masses of the residual uplands that told a clear story.

The legitimate inference was that the suspension of glaciation had suspended as well a process which had threatened truncation of the range. It was obvious, postulating recession, that the canyons of this summit region were independent in their courses, and had developed independently, of the initial upland drainage plan. It was clear, from their grade profiles, that they were not stream-cut. The inference was not only legitimate, but necessitated, that, profoundly deep as they were, they were essentially of glacial excavation.

Here, then, were facts of observation in support of one of the two extreme views referred to at the outset. That, however, ice-streams had descended on the long western slope to the range foot, or even close to it, I subsequently found to be untrue.

The canyons of that flank I now regard as stream work below, as ice work above, and as the joint product of streams and of glaciers, alternately, in between. But wherever they are abnormally deep, I infer from the evidence of the floor profiles that they have been thus deepened by glaciers.

The range had not been domed over by a continuous ice-sheet; it had been glaciated rather against its upper slopes. The summit tracts, narrowed by flank attack, had remained bare, perhaps because wind-swept; the ridges and peaks of degradation continued emergent, because sharp. Obviously, though its period had been short, the action of the process had been relatively rapid; for in the shallow preglacial canyons of the broad foothill zone, in which lay the moraines of the outer glacial boundary (the relatively insignificant, coarse products of degradation), the normal processes of erosion had accomplished so little that, seemingly, their action there had been suspended.

The summation of the hypothesis was that retrogressive cutting in large part had carried away the uplands, along an approximately definite, and an approximately level, plane of attack. Deep canyons had resulted, indirectly, because recession, directed horizontally, had been directed into a rising grade. This action seemed distinct from

that of abrasion. Abrasion accomplishes deepening vertically and directly. In the case of a "continental" glacier upon a level plain, abrasion would be operative alone. But that process was not to be invoked in explanation of the scalloped, tabular forms of the High Sierra; these pointed only to basal sapping.

Basal sapping in its details, however, was unintelligible. It was not immediately apparent, at least, how a glacier, originating against a precipitous rock slope, and drawing away from that slope, could undercut and cause it to recede.

To return to the narrative form, one feature of the small ice-body lying deep in a great amphitheater opening northward from Mount Lyell—one of perhaps a dozen "glacierets" of the High Sierra—seemed to offer the explanation.

Among the numerous crevasses or schrunds of several diverse systems sharply lining the snowy surface upon which I looked directly down as upon a map, one master opening, the *Bergschrund* of the Swiss mountaineers, paralleled the amphitheater wall, a little out upon the ice. In detail it was ragged and splintered, but its general effect was that of a symmetrical great arc. I had already in mind, vaguely formulated, the working hypothesis that the glacier makes the amphitheater; that it is not by accident that glaciated mountains, and such mountains only, abound in forms peculiarly favorable to heavy snow-drift accumulation. My instant surmise, therefore, was that this curving great schrund penetrated to the foot of the wall, or precipitous rock slope, and that a causal relation determined the coincidence in position of the line of deep crevassing and the line of the assumed basal undercutting.

So much of assumption, so plausibly grounded, rendered direct observation at this critical point on the glacier floor compellingly desirable; and, returning to camp for all hands and the pack ropes, the rather appalling task was in fact very easily accomplished.

The depth of descent was about one hundred and fifty feet. In the last twenty or thirty feet, rock replaced ice in the up-canyon wall. The schrund opened to the cliff foot. I cannot say that the floor there was of sound rock, or that it was level; but there was a floor to stand upon, and not a steeply inclined talus. It was somewhat cumbered with blocks, both of ice and of rock; and I was at the disad-

vantage, for close observation, of having to clamber over these, with a candle, in a dripping rain, but there seemed to be definitely presented a line of glacier base, removed from five to ten feet from the foot of what was here a literally vertical cliff.

The glacier side of the crevasse presented the more clearly defined wall. The rock face, though hard and undecayed, was much riven, its fracture planes outlining sharply angular masses in all stages of displacement and dislodgment. Several blocks were tipped forward and rested against the opposite wall of ice; others, quite removed across the gap, were incorporated in the glacier mass at its base. Icicles of great size, and stalagmitic masses, were abundant; the fallen blocks in large part were ice-sheeted; and open seams in the cliff face held films of this clear ice. Melting was everywhere in progress, and the films or thin plates in the seams were easily removable.

These thinning plates, especially, were demonstrative of alternate freezings and thawings, in short-time intervals, probably diurnal. Without, upon the cirque or amphitheater wall, above the glacier, such intervals would be seasonal. Thus, apparently, to generalize from observation at a single point, the arc of the bergschrund foot, and the coincident arc of the cirque-wall foot, is a narrow zone of relatively vigorous frost-weathering. The glacier is a cover, protective of the rock surface beneath it against changes of temperature. Probably the bed temperature does not fall below that of melting ice. Hence, if (in summer) the bed at the wall foot is exposed, through the open bergschrund, to daily temperature changes across the freezing-point, frost-weathering must be sharply localized. The glacier will be efficient as the agent for débris removal; the result, therefore, must be quarrying and excavation, and basal sapping.

The amphitheater floor has been described as characteristically reversed in grade, though at a slight angle, and ponded backward against its head wall. It may be assumed that the disrupting action of frost at the bergschrund foot is directed against the floor, as well as against the cliff. Likely enough, also, the glacier is a highly efficient agent for removal, supplementing, by "plucking," the initial rupturing work of frost. Its plucking action may be directed downward as well as backward; but downward action, at an early

stage, will be defeated by the rapidly increasing difficulty of waste removal. The great arc-form crevasse at the glacier head, therefore, may be the indirect cause, not merely of recession of the canyon head at a low grade into a high grade, but of recession at a grade declining from the horizontal. Apparently there is a limit to such extension—a limit the earlier reached, the sharper the acclivity of the upland surface into which channeling is extended; and the head wall, in consequence, breaks back into steps, successively shortening in length of tread. The rearward steps may continue to be marked by schrunds rising to the glacier surface; living glaciers, in fact, are often characterized by "cascades" in their upper courses; but sharply defined cross-cliffs, in empty glacial canyons, are rarely to be found far down-stream. Presumably they are so deeply buried there as to be wholly left to the dulling influence of scour. The "rock-basin" lakes of the bare floors toward the head have received more attention than the great bowl of the amphitheater itself, the most phenomenal of all constantly recurring mountain forms; but I suspect that they are even more significant than has been supposed.

The hypothesis as to the action at the bottom of the bergschrund, in explanation of sapping, is slenderly supported. Physiographic inquiry has been an avocation merely, and I have failed of opportunity to repeat and to extend my early observations. Those observations, furthermore, were hastily and somewhat carelessly made, and were not recorded at the time. But that deep basal sapping, in massive rocks especially, as in the summit region of the High Sierra, accounts for the anomalies of towering upland remnants, of canyons gradeless for miles, and of the sharp scalloping in ground-plan everywhere to be observed, is at once apparent, I think, upon full recognition of the forms themselves.

With these destructional effects assigned to glacial agency, a novel possibility is at once suggested as to the part played in their persistent development by glacial scour, or coarse abrasion. The upright element in the profiles, it would seem, must be regarded as a sapping effect in which scour plays no part at all. But the approximately horizontal element, considering its great extension, often, and the relatively abrupt descent by which compensation is made, constitutes a difficulty no less. The adjusted grade in river erosion is

a smooth curve, lessening in declivity in the direction of flow. The glacier, however, by ablation, is diminished in volume as it lengthens; it is normally deepest close to its head; and possibly it is most effective in scour-erosion in proportion as it is deep. It must, in that event, tend to produce a valley "down at the heel."

The reverse grade, on amphitheater floors especially, occurs with sufficient frequency to be regarded as a type form. Rock-basin lakes, beginning at the amphitheater head, sometimes have notable length, several times the canyon width. The upper surface of the glacier here, on the other hand, invariably declines forward. Thus, in specific instances, it is not merely inference, but fact, that the glacier is deepest at the rear, and excavates there to a forward-rising grade.

It is, furthermore, implied that forward inclination of bed is not essential to glacier movement. It is not necessary, merely to determine that question, to inquire intimately into the nature of glacial motion. Fundamental in that motion, apparently, is the weight of the ice; and if the glacier at bottom, under its own weight, is not strictly viscous, it is apparently at least viscoid, responding in effect to the law of liquid pressures.

A viscous substance, heaped upon a level surface, spreads in mounded disk form, deepest at the center. Its flow-curve, in any radial vertical plane, advances from the bottom. The tendency to flow movement is proportioned to depth—to load; it diminishes toward the outer margin. The outer portions, therefore, move too slowly, and are affected by horizontal, forward thrust. They are retarded at the same time by basal friction, and in consequence present a bulged and swelling front, implying, over a broad marginal tract, rising lines of flow. But the glacier is terminated forward, and is thinned toward its termination, by combined melting and evaporation—*i. e.*, by ablation; and, by ablation, it may be inferred, the constantly bulging front is planed away. The glacier may be regarded as made up of two layers—a superficial, relatively rigid layer, and a basal layer, mobile under the weight of the other; or of a zone of fracture and a zone of flow. In the thinning frontal region, the upper layer, or cover, is brought into contact with the bed. Rearward, it is lifted; though at the same time there it is planed away. Hence, rising lines of flow in effect extend to the surface; for the cover is to

be regarded as a zone of rigidity merely, constant only as to position, and thickening, from the mobile ice below, as it is thinned by ablation above. Rates of glacial motion, measured along the surface, therefore will be deceptive. On these assumptions, the line of most rapid advance in the glacier mass is from near the bed, at the rear, to the surface, near the front. Along the bed, motion slows forward; and as pressure upon the bed diminishes in that direction, presumably abrasive erosion is most vigorous toward the rear. The accepted view as to the flow-curve of the river is that, normally, it advances most rapidly at the surface. Deep rivers, however, are found to advance from a point measurably below the surface. If rivers had the great depth of glacial streams, possibly it would appear that the curve of flow which they actually have is but the reverse curve due to bed friction, extended to the surface because the surface is near. It would seem to be a safe assertion that descending grade of bed is not essential to river motion, only decline of the river surface toward the level of discharge; and that, in a long canyon with level floor, terminating at the sea, a river, one or two thousand feet in depth and maintained at that depth at its head, would advance with essentially the same flow-curve as that here attributed to the glacier. The value of such speculation consists in the indication it affords that appeal to the observed flow-curve of the river, in rebuttal, may not be valid.

The long ribbon meadow of the lower canyon course, no less than the ponded amphitheater floor, I think, invites interpretation as the manifestation of a tendency on the part of the glacier to channel excessively up-stream. And in this overdeepening toward the canyon head, I suspect, the two agencies of horizontal sapping and of vertical corrosion powerfully co-operate.

The ultimate effect, upon a range of high-altitude glaciation, would be rude truncation. The crest would be channeled away, down to what might be termed the base-level of glacial generation. Where, among the determining causes of glaciation, high latitude rather than high altitude is operative, the base-level of degradation may lie below the sea, deepest centrally and shallowing outward. Given a land area initially, the glacier itself, as degradation approached its maximum, would replace the land, affording the

necessary above-sea surface for snow accumulation. The degradation limit would be determined by the lifting power of the sea.

The hypothesis, at this stage, is of much less importance than recognition of the anomalies of fact, of which it offers a tentative, even venturesome, explanation. In the fiorded regions of the globe, notably in the Patagonian Andes, of which a well-controlled reconnaissance survey has recently been completed, we have examples not only of fiords deepening backward for many miles into rising grades, but of fiord lakes, in parallel series, penetrating from foothills on the one side to foothills on the other, transecting a range. In explanation of such deep channels, whether occupied by arms of the sea, by lakes, or by feebly moving streams on meander bottoms, the appeal to grades, it seems to me, will be most cogent.

WILLARD D. JOHNSON.

WASHINGTON, D. C.

SYSTEMATIC ASYMMETRY OF CREST LINES IN THE HIGH SIERRA OF CALIFORNIA.[1]

THE substance of the present paper was communicated to the Section of Physiography of the Congress of Arts and Science at St. Louis last September. The section had just listened to Mr. Johnson's paper on "The Profile of Maturity in Alpine Glacial Erosion" (this JOURNAL, pp. —). Mr. Johnson stated that since his first observations in the Sierra in 1883 his ideas as to the explanation of the phenomena had undergone development, and he regretted that he had been unable to revisit the region for purposes of verification. It was therefore a matter of gratification that I was able to supplement his presentation by the statement that during two seasons of exploration in the glaciated district of the Sierra I had found his hypothesis of cirque development by glacial sapping of the utmost utility in the explanation of the topography. It happened also that its utility was illustrated in my discussion of the origin of the special features to which my own communication referred.

In the higher part of the Sierra Nevada the glacial cirque is a conspicuous feature of the topography. Each main crest of the great mountain mass, as a rule, is bordered on each side by a row of cirques facing outward. Separating the cirques on the same side of the main ridge are subordinate ridges or spurs. Gradually the cirques unite to form glacial troughs, and these troughs are separated, at a somewhat lower level, by ridges constituting subordinate features of the range. Some of the ridges between cirques and between troughs are equally steep on both sides of their crest lines, but many —a large minority—are notably steeper on one side than on the other, and this asymmetry of cross profile is definitely related to the cardinal points. Ridges trending east and west are steeper on the north side than on the south, those trending north and south are steeper on the east side, and those trending northwest and southeast are steeper on the northeast side. In general, the gentler slope has the grade of a steep roof, and it is often clothed by rock fragments approximately

[1] Published by permission of the director of the U. S. Geological Survey.

in situ. Ordinarily it is too steep for the horse, but is readily scaled by the mountaineer. As a rule, the steeper slope either is constituted by, or else includes, an abrupt cliff which at most points cannot be climbed. Fig. 1 shows a group of high ridges in which the steeper faces are turned to the north, and Fig. 2 a group in which they are turned to the northeast.

FIG. 1.—Eastward from Mount Gardiner, Sierra Nevada. Compare the southward (right) slopes with the north-facing cliffs. [Photograph by J. N. Le Conte.]

These slopes are not controlled by rock structure. The principal rock is granite, and this granite is in large part structureless. Where it is traversed by joint systems the details of sculpture are greatly influenced by the joints, but the trend and slope of the greater features are independent of the joints.

A little reflection shows that the distribution of steep slopes is correlated with the alimentation of Pleistocene glaciers. The southward slopes of the east-west ridges, because turned toward the sun, lost more snow by melting and evaporation than did the northward slopes, and a smaller fraction of the snowfall they received remained

to nourish glaciers. Thus the glaciers resting against the southward slopes were comparatively ill fed, and the glaciers of the northward slopes were comparatively well fed. The north-south ridges may be assumed to have been swept, then as now, by dominant westerly winds, which carried much snow from the westward slopes over the crests to the eastward slopes, where it accumulated; and thus the glaciers resting against the eastward slopes were better nourished than those of the westward. These peculiarities of snow distribution

FIG. 2.—Southeastward from Alta Meadows, Sierra Nevada. Compare the northeast-facing walls of the high glaciated valleys with their southwest-facing walls.

may be readily observed at the present time. If one stands, late in summer, upon a peak in the midst of the glaciated district and looks toward the east or north, he sees bare rock, with only here and there a small remnant of snow; but if he turns toward the west or south, he looks upon a patchwork of snow and rock in which the predominance of the rock may not at once be apparent. Fig. 7 illustrates the relations of surviving snowbanks in early summer to northward and southward slopes.

It can hardly be doubted that the distribution of Pleistocene snow deposition stands in causal relation to the distribution of asymmetry in the crest lines of the minor ridges. And it is in explanation

of this relation that I avail myself of Johnson's hypothesis. Each glacier which receives more snow on one side than on the other adjusts its cross profile to a condition of equilibrium by moving away from the region of greater supply to the region of lesser supply. This lateral motion is, of course, combined with the general, and more rapid, forward motion of the glacier, but it is nevertheless competent to produce at the side of the glacier phenomena quite similar to those at the head. Fig. 3 shows diagrammatically the ground plan of a glacier flowing southward. The greatest snow accumulation is in the cirque, *AA*, where precipitation is at a maximum, where depletion through solar influence is at a minimum, and where circling cliffs protect against removal by the wind. There is great accumulation also along the west margin, *BB*, where the snow drifted by the westerly winds comes to rest in the shelter of the west wall of the glacier trough. Along the eastern border, *CC*, the snow deposit is comparatively small, because of exposure to the westerly winds. The resulting lines of ice-flow are as drawn. Moving directly away from the walls of the cirque, the glacier makes and annually renews the bergschrund, *ab*. Moving obliquely away from the west wall of the trough, the glacier similarly produces the minor bergschrund *bc*, and this minor bergschrund leads to sapping and the production of a cliff, just as the major bergschrund causes the cirque cliff. Thus the west wall of the trough is kept steep, and is thereby contrasted not only with the east wall of the same trough, but with the east wall of the adjacent trough, so that the rock crest between the two troughs is not symmetric.

Usually in viewing a cirque it is possible to trace about its wall a somewhat definite line separating a cliff or steeper slope above from a gentler, usually scalable, slope below. This line I conceive to mark the base of the bergscrhund at a late stage in the excavation of the cirque basin. I have called it in my notes "the schrund line." It can usually be traced for some little distance beyond the cirque, and sometimes for several miles on one wall or other of the glacier trough. Advancing along the trough wall, it descends gradually with a slope which may be assumed to represent the gradient of the ice surface, that surface having been somewhat higher than the schrund line. Its expression outside a cirque may be seen in Figs. 2, 5, and 6.

At a somewhat lower level than that to which the preceding para-

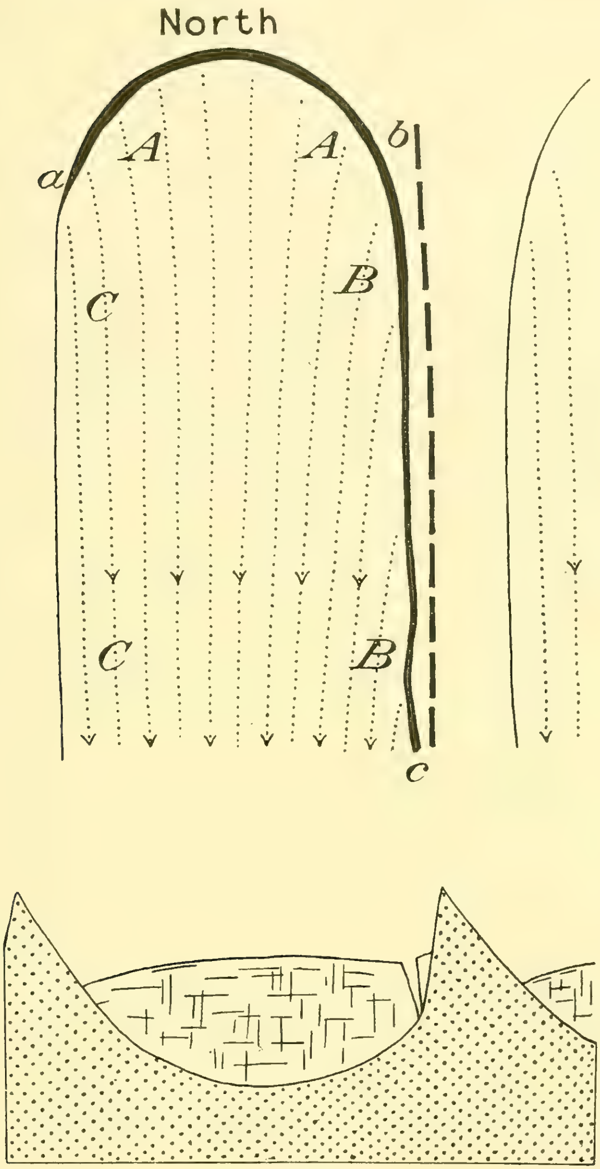

FIG. 3.—Diagrammatic ground plan and section of a glacier. The heavy line *abc* marks the position of the bergschrund. Dotted lines show direction of ice flow. The broken line marks the crest of the spur separating the glacier from its neighbor on the west.

FIG. 4.—Eastward from Mount Conness, Sierra Nevada. In the foreground is the upper edge of a small glacier with its head cliff and bergschrund. Farther away the descending continuation of the same cliff springs from a schrund line, the exact position of which is masked by a lingering snow-drift.

graphs apply, the Pleistocene glaciers occupied a smaller share of the surface, and there are considerable unglaciated areas. The photograph shown in Fig. 6 was made in this region. The view is westward up the trough of a glacier. Beyond the head of this trough is another glacier trough descending westward, and the dividing ridge was partly destroyed by the head-erosion of the glaciers, so that the typical amphitheater is not shown. The south wall of the

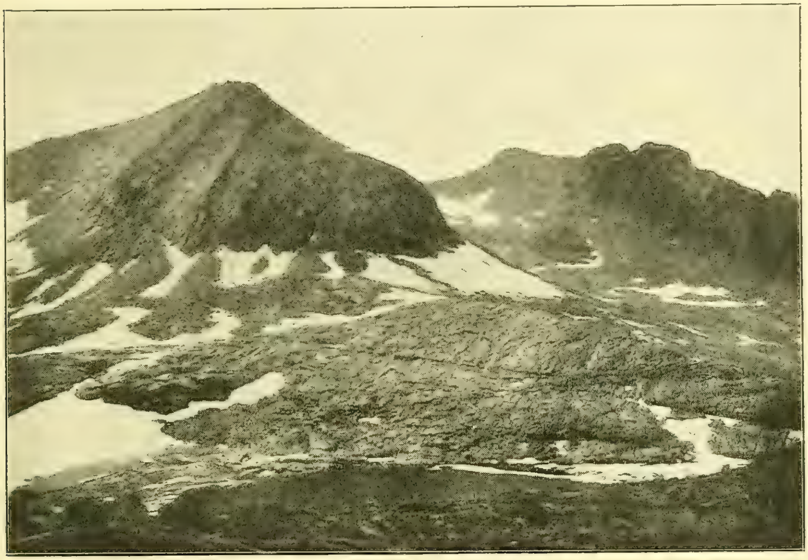

Fig. 5.—Spur between two glacial amphitheaters near Mount McClure, Sierra Nevada, showing schrund line.

trough is steep, and shows distinct evidence of sapping. The cliff at top, being composed of thoroughly jointed granite, does not stand vertical, and the fragments recently fallen from it have built a talus which conceals the schrund line. But it is evident that here the sapping action at the schrund line was more active than the glacial erosion lower down on the slope, so as to create a sort of shoulder or terrace near that level. Stating the interpretation in another way, the excessive alimentation along the south wall of the glacier was here developing a branch glacier and a tributary cirque. This cirque was eating its way back into the ridge bounding the glacier.

On the opposite side of the ridge are gentle slopes, in part of preglacial origin. Perhaps all the portions visible are of that character, but on that side of the ridge are also faintly developed cirques, from which small ice-streams flowed toward the south.

At still lower levels are many ridges along which Pleistocene

FIG. 6.—Westward from Kid Peak, Sierra Nevada. The highest point of the crest at left is Goat Peak.

glaciers were developed on one side only—the north or northeast side, so far as observed. The south and southwest slopes retain the preglacial facies, and retain also the actual preglacial topography, except for such equable reduction of surface as may have been accomplished by aqueous and atmospheric agencies. The direction of ice movement in such cases was not parallel to the ridge axis, but approximately normal to it. The glacial excavation did not always take the character of a series of cirques, but sometimes produced a

continuous cliff, running with moderate undulation parallel to the ridge axis.

I have no photograph representing this topographic type in its purity. Fig. 7, exhibiting a ridge of greater altitude, serves to show a somewhat similar cliff, wrought by glacial head-erosion but imperfectly divided into cirques, and culminating in a crest from which nonglacial profiles descend in the opposite direction. But the example

FIG. 7.—Westward from Mount Hoffmann, Sierra Nevada. Compare the glacial topography of the north (right) face of ridge, with the nonglacial profiles toward the south. [Photograph by A. C. Lawson.]

differs from the type in the stronger expression of the ice-work, in the comparatively high grade of the nonglacial profiles, and in the fact that those profiles, as seen in the photograph, conceal south-facing cirques of some magnitude.

The asymmetry of these lower ridges is more pronounced than that of any others, because instead of contrasting two phases of glacial erosion they contrast glacial with nonglacial. It is worthy of note also, though not strictly germane to my subject, that the contrast in sculpture of the two ridge slopes serves to compare the efficiency of subaërial degradation with that of one phase of glacial

degradation. The glaciers of these low ridges, being able to develop only on the slopes most favorable for snow accumulation, marked the lower limit of névé conditions and were the feeblest of all the Sierra glaciers. Their lives must have been short, for they could exist only when glacial conditions were at or near a maximum; they began long after, and ceased long before, the glaciers of the higher districts. The topographic features they produced were subject to

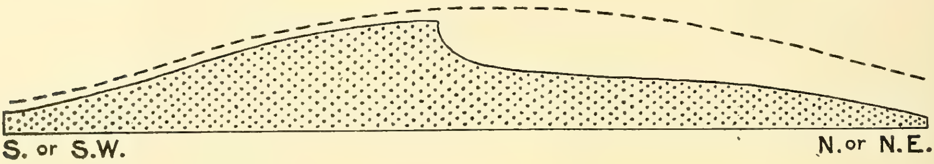

FIG. 8.—Diagrammatic cross-section of a ridge glaciated on one side only, with hypothetic profile (broken line) of preglacial surface.

the dulling influence of atmospheric and aqueous attack during both interglacial and postglacial times. And yet the degradation they accomplished was far greater than that of nonglacial agents working on the opposite sides of the same ridges—agents working not only during the same time, but during all interglacial epochs and during postglacial time. It is true that we cannot measure the nonglacial work, which consisted of a general reduction of surface without notable change of form; but whatever the amount, we may assume that it would have been the same on both slopes of the same ridge, had there been no glaciers. The visible ice-made hollows therefore represent the local excess of glacial over nonglacial degradation.

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THE PROBLEMS OF GEOLOGY.[1]

THE subject "The Problems of Geology" was assigned to me. I should not have ventured to select so formidable a topic for a brief address.

RELATIONS OF THE SCIENCES.

We are all aware that geology is a many-sided subject. While at the outset it was a simple observational study, it soon developed physical, chemical, astronomical, and biological sides. The importance of these different sides has continuously increased, so that we now often speak of physical geology, chemical geology, astronomical geology, and biological geology.

To appreciate the position of geology among the sciences it is necessary to go back to fundamental definitions. Natural philosophy in the old and broad sense may be defined as the science which treats of energy and matter. But investigations have shown that the ether also must be considered, and hence this definition needs modification. Some physicists have been inclined to extend the scope of the term "matter" to include matter in the old sense and also ether. But it seems to me that until the two, which appear to be so different, are shown to be essentially one, it is better to use the term "matter" strictly in its old sense. But it is advisable to have a term which shall include both matter and ether, and for this place the word "substance" seems suitable.[2] Using the term in this sense, natural philosophy may be defined as the science which treats of energy and substance.

Physics is the science which treats primarily of energy; chemistry is the science which treats primarily of matter. Thus physics considers mainly the actions and transformations of energy through

[1] The principal address given in the Department of Geology of the International Congress of Arts and Science at St. Louis, 1904.

[2] This definition of the word "substance" is different from that of Holman, who, as I understand it, makes the term so comprehensive as to include matter, ether, and energy. By him the word "matter" is apparently used to comprise what is here covered by both matter and ether.—SILAS W. HOLMAN, *Matter, Energy, Force and Work*, pp. 135 ff.

matter and ether; and chemistry considers mainly the actions and transformations of matter through energy. But since energy is manifest to the senses only through matter, and since matter does not exist without manifestations of energy, the relations of the two sciences are very intimate. In any book upon either subject the treatment constantly passes over to the other; indeed, energy and matter are inseparable—one cannot be considered without the other. Recently the relations between physics and chemistry have become even closer by the rise of the intermediate science, physical chemistry. This science completely bridges the gap between the two and unites them as a whole into the conjoint science of physics-chemistry, which is the science of energy and substance. As thus defined, physics-chemistry becomes a synonym of natural philosophy in its broad sense.

While physics and chemistry are really a single science, it is to be repeated that the chief point of view of physics proper is that of energy, and the chief point of view of chemistry proper is that of matter. This will be appreciated if one but mention the subjects considered in text-books of physics and chemistry. Some of the subjects of physics are sound, heat, light, and electricity. These are all forms of energy. The chief subjects for consideration by chemistry are the elements and their combinations, such as helium, chlorine, iron, calcium carbonate, etc. These are all forms of matter. Since physics-chemistry treats of all the energy and substance within the reach of our senses, physics and chemistry are the two sciences the principles of which are believed to be applicable to the entire visible universe.

Astronomy treats of energy and substance in the heavens. It is concerned primarily with the nature and development of the heavenly systems. Under the above definition, astronomy is the science of the physics and chemistry of the heavens. Biology treats of energy and substance in living organisms. Under this definition, biology is the science of the physics and chemistry of organisms. Geology treats of the energy and substance of the earth. Under this definition, geology is the science of the physics and chemistry of the earth. It includes mineralogy. These definitions may not be complete, but at least they are true so far as they go.

It is not necessary for present purposes, to consider the possible defects of the definitions given, except that for geology. Objections may be raised to defining geology as the science of the physics and chemistry of the earth, on the ground that this definition is inadequate to cover descriptive and historical geology. It may be said that it is a part of geology to describe the facts exhibited by the earth as they appear, without reference to physics or chemistry. It may be said that the history of events, as shown by the rocks and fossils, does not necessarily require physical or chemical treatment. There is some truth in these statements, but on the other side it may be held that the facts are the results accomplished by physical and chemical work. These facts become important and significant mainly as they are interpreted in physical and chemical terms. The objects of the earth—the complex results of chemical and physical work—if described without reference to the manner in which the results came about, have comparatively little interest. In reference to historical geology it may be said that this subject gives a chronological arrangement of the results of chemical and physical work.

It thus appears that physics and chemistry are the elementary sciences, while astronomy, biology, and geology may be defined, possibly with some lack of completeness, as the applications of the principles of physics and chemistry to various complex systems. In this sense astronomy, biology, and geology are applied sciences.

We are now in a position clearly to indicate the relations of geology to the sciences mentioned. So far as the earth is one member of one of the heavenly systems, it is a subject of astronomy. So far as organisms constitute a small part of the earth, they are the subject of geology. Since the earth is one of the subjects of astronomy, and since the entire kingdom of organisms constitutes a small part of the material of the earth, geology is closely related on one side to astronomy, upon the other side to biology. Geology is one of the children of astronomy. Geology begins with the earth at the time of its astronomic birth. As geology is one of the children of astronomy, so biology is one of the children of geology. As the result of various processes upon the earth, chemical and physical, organisms have been formed, and have gone through their long and complex development. But astronomy, geology, and biology—grandparent, parent,

and child—have long existed side by side, and their interaction and mutual effects have been most profound. One cannot be comprehended independently of the others.

While geology is very closely related to astronomy and biology, we have seen that it is still more closely related to physics and chemistry. Since physics-chemistry is the science of energy and substance in general, and since geology is the science of the energy and substance of the earth, geology is not simply related to those subjects—it rests upon them as its one secure foundation. They are the elementary sciences upon which geology is based; for they are the sciences of all energy and substance of which the object of geological science is an insignificant fraction.

We have now reached the most fundamental problem of geology—the reduction of the science to order under the principles of physics and chemistry. To a less extent geology is subject to the sciences of astronomy and biology.[1]

While the relations of geology to the other sciences, as above set forth, are incontestible, it was possible to appreciate those relations only after the sciences were well developed. Geology did not begin consciously as the science of the physics and chemistry of the earth. The phenomena of the earth were studied as objects, and thus geology

[1] The earth is the vastest aggregate of matter within the direct reach of man. By a study of a small part of this aggregate the principles of physics and chemistry have been formulated. The material which has been studied is but an inappreciable part of the material of the earth, and but an infinitesimal part of the substance of the universe. Yet the doctrine is unhesitatingly accepted that the principles of physics and chemistry, wrought out with reference to this minute fraction of substance, are not only applicable to all the materials of the earth, but to all parts of the visible universe. This daring generalization has received astonishing confirmation by studies of other portions of the visible universe through the spectroscope and photographic plate.

In the generalization that the principles of physics and chemistry, developed by study of small masses of material, apply to all parts of the universe, we have a case of the extension of a generalization from a part to the whole, which surpasses almost any similar extension of reasoning. Indeed, some philosophers have seriously questioned the legitimacy of the conclusion.

In view of the foregoing, it is rather curious that the geologist now finds his most important problem, the problem of problems, in the explanation of phenomena exhibited by the heterogeneous earth in terms of those principles of physics and chemistry built up mainly by observation, experiment, and reasoning upon a minute fraction of the earth.

was at first an observational study. The next step, a revolutionary one, was to explain the observed phenomena in terms of physical and chemical processes, many of which could be observed. But few have asked the question: "What is a geological process?"

GEOLOGICAL PROCESSES.

It is a curious fact that, while the word "process" is used in innumerable geological papers and text-books, I have been unable to find anywhere a definition of a "geological process."

I shall define a "geological process" as the action of an agent by the exertion of force involving the expenditure of energy upon some portion of the substance of the earth.

Physical definitions of "force," "work," "energy," and "agent."— In order to understand the above definition of "geological process" it is necessary to define the terms "force," "work," "energy," and "agent."

Hoskins defines "force" as action exerted by one body upon another tending to change the state of motion of the body acted upon.[1] According to Daniell's more simple definition, "force" is any cause of motion.[2]

When a force applied to a body moves the body in the direction toward which the force acts, it does work.[3] In this sense "work" is the product of force into displacement, the common formula being $W = FS$. The unit of work is defined as the quantity of work done by a unit force acting through a unit distance.[4]

Hoskins defines "energy" in the terms of force and work. Thus he says when the condition of a body is such that it can do work against a force or forces that may be applied to it the body is said to possess energy. The unit of energy is the same as that of work.[5] According to Daniell's more simple definition, "energy" is the power of doing work.[6]

The order of definition of the above terms is that in which knowledge of them has developed. The actions of forces in doing work are

[1] T. M. Hoskins, *Theoretical Mechanics*, 1900, pp. 2 and 16.

[2] Alfred Daniell, *A Text-book of the Principles of Physics*, 3d ed. (1895), p. 4.

[3] Hoskins, *op. cit.*, p. 298.

[4] *Ibid.*, p. 298.

[5] *Ibid.*, p. 308.

[6] Daniell, *op. cit.*, p. 2.

observed. From such observations the existence of energy is inferred. Wherever forces act upon matter and work is done, energy must exist. Further reasoning shows us that bodies may possess energy which is latent and is not exerting force. Hence many physicists have defined "energy" without introducing the words "force" or "work." Thus, according to Holman, "energy" is power to change the state of motion of a body.[1] If energy be recognized as the primary thing, then "force" can be defined in terms of energy. According to Holman, "force" is that action of energy by which it produces a tendency to change the state of motion of bodies.[2] Similarly, the word "energy" may be introduced into the definition of the word work. Thus Holman says "work" is that action of energy by which it produces motion in a free body, or produces or maintains the motion of a body against resisting forces.[3]

An "agent" is any portion of the substance of the earth which may exert force and thus expend energy to perform geological work. Thus ether, air, water, and rock are agents.

The next step in the comprehension of geological processes is a consideration of the kinds of energies, forces, and agents, and their relations.

Kinds of energy and force.—Ultimately the forms of energy may be reduced to a few, and possibly to a single kind. Indeed, some physicists believe that all forms of energy are really but different manifestations of kinetic energy. But the number of elementary kinds of energy in the universe is a problem for the physical philosopher, not the geologist. The geologist is concerned in all the kinds of energy which he observes at work. These are: (1) gravitation energy, (2) heat, (3) elasticity energy, (4) cohesion energy, (5) chemical energy, (6) electrical energy, (7) magnetic energy, (8) radiant energy (including radiant heat, radiant light, and electro-magnetic radiation).[4]

From another point of view energy may be classified into kinetic energy and potential energy. Under static conditions of all the parts of a system any or all of the kinds of energy above named may be exerting force, but so long as no motion occurs and no work is done they are all potential. When anywhere in the system move-

[1] Silas W. Holman, *Matter, Energy, Force and Work*, 1898, p. 20.

[2] *Ibid.*, p. 41. [3] *Ibid.*, p. 17. [4] *Ibid.*, p 37.

ment takes place and work is done, some portion of the energy becomes kinetic. Work and kinetic energy are inseparable. As multifarious kinds of work are always going on in the world, potential and kinetic energy are always existent. For the most part we can trace the kinetic energy back to one or more of the various classes of energy above mentioned, but some part of it may be derived from other unnamed sources.

Any of the forms of energy may exert force, hence we have the terms "force of gravitation," force of heat," "force of elasticity," "force of cohesion," "chemical force," "electrical force," "magnetic force," and "radiant force."

Any or all of these forces may be exerted both under static and dynamic conditions. When the conditions are static, the energy is potential. When the conditions are dynamic and work is done, some portion of the energy is kinetic. To illustrate: For many years a cliff may stand; but finally a portion of it falls and geological work is done. The force of gravitation is exerting the same pressure upon the material concerned during all the years of quiesence and during the brief period of movement, and for that matter continues to be exerted after movement ceases. During the static conditions the energy of gravitation is potential. During movement some part of it, by pressure of the force of gravitation, passes into kinetic energy. And this energy, through the agency of the falling part, the agent, does further geological work upon the material at the foot of the cliff.

All of the forms of energy and force are important in geology, but the geological work of some of them has been more clearly discriminated than that of others. For instance, the geological results produced by electricity and magnetism have not been worked out, although I have no doubt that electrical and magnetic energy have produced important permanent effects upon the earth which ultimately will be discriminated.

Geological use of the words "force," "energy," and "work."— To the present time the geologist has much more frequently used the word "force" than "energy." This is because the geologist is usually more concerned with the exertion of force by an agent than he is with the source or amount of energy which the agent contains. Physical investigations seem to show that substance contains enor-

mous quantities of energy, only a small part of which is manifest to the senses, and this only under special circumstances. So far as geological bodies have great stores of energy which are not manifest as force, there is no change of condition—no geological process. The geologist is primarily concerned with the energy which is manifesting itself either statically or dynamically by the exertion of force. Consequently, he more often refers to the forces of geology than the energies of geology. This is the more natural since the unit of force and the unit of energy are the same, and that energy is measured only by its action as a force. While in the past the primary interest of the geologist has been in force rather than in energy, it is probable that in the future he will become more and more concerned in the energy itself and its sources.

Often the geologist has made no discrimination between the words "force" and "energy." He has frequently used "force" in the old sense, both to cover the thing itself, the energy, and the action of energy, the force, in accomplishing work. This formerly was the practice of physicists also, who, for instance, spoke both of the conservation of force and the exertion of force. If the conclusion be correct that the source and amount of energy concerned in a process should be discriminated from its action as a force, it is clear that the time has now come when the geologist must in his writing clearly differentiate the two ideas.

Since the physicist now makes an important discrimination between the words "energy" and "force," it may be necessary for the geologist to follow him in his definitions of these words, although much can be said against technicalizing and narrowing the use of the general term "force." Probably the interests of all the sciences would have been best subserved if the physicists had introduced a new word for the technical sense assigned to the word "force," and had left this term to be used in the general way in which it has been used in the past in science, and will continue indefinitely in the future, to be used in literature. This is especially true since, if we confine the word "force" to its physical definition, we are in constant need of a word to cover both energy and force, as defined by the physicists. If the latter word be technicalized, I can think of no better word than "power" for the conception which includes both. This

was the word used for this place by Hutton in the opening pages of his epoch-making paper on the "Theory of the Earth."[1]

It is also to be noted that the word "work," as above defined, is also technicalized, having reference only to the exertion of force in producing change of state of motion. With this meaning it has no relation to the material results. To illustrate: By the expenditure of energy, the crust of the earth may be fractured, or material be transported from one place to another. In the general sense used by geologists, these results are often spoken of as "work." It is certainly a very grave question whether geologists can afford to restrict the word "work" to its physical definition, and thus be obliged to discontinue its use in an indefinite sense, both for the expenditure of the energy, and the effect of such expenditure, or for either alone. While this is so, it may be said there are very considerable advantages in having a technical word for the physical meaning of work. This would assist the geologist to think clearly and discriminate between the expenditure of energy and the material effects of such expenditure.

Whatever meaning the geologist assigns to the words "force" and "work," he should have a clear understanding of the conceptions which the physicists have of their meaning, and should attempt to express these conceptions in some way. Also he should make it clear, in case he decides not to use the words "force" and "work" in the physical sense, that the old general usage is retained for them. In this paper I shall use "force" in its technical sense, but retain the common usage for the word "work."

The agents of geology.—We are now ready to classify the agents of geology. They may be grouped into ether, gases, liquids, and solids. Possibly organisms are so peculiar a combination of gases, liquids, and solids that they should constitute a fifth group, and in this case the agents may be classified into ether, gases, liquids, solids, and organisms. From another point of view the agents may be classified into their chemical elements, some seventy or more in number, but of which only about twenty are so abundant as to be important.

The small number of categories of energies and agents given

[1] CHARLES HUTTON, "Theory of the Earth," *Philosophical Transactions of the Royal Society of Edinburgh*, 1785, pp. 212–14.

might lead to the conclusion that the subject of geology is reduced to simpler terms than is really the fact. Each of the forms of energy, gravitation, heat, elasticity, cohesion, chemical affinity, electricity, magnetism, and radiation is most complex and acts as forces in most diverse ways. The number of gases, of liquids, and of solids which occur in nature are beyond number. They are most diverse in character. For instance, the liquids vary from nearly pure water to magma. The solids comprise all kinds of minerals, of which there are many hundreds, and the various combinations of these minerals in rocks, the different phases of which are very numerous. Gas without the presence of liquids and solids, liquids without the inclusion of gases and solids, and solids which contain no gases or liquids, while perhaps possible in a physical or chemical laboratory, are not found in nature. As remarked by Powell, gases, liquids, and solids are everywhere commingled upon the earth. All are commingled with ether. Thus the various combinations of agents are beyond computation. Also definite agents, for instance water may occur in various kinds of bodies, each of which acts in a manner peculiar to itself.

The materials upon which the agents act are of the same kinds, and have the same diversities and complexities, as the agents themselves. Moreover, the work done inevitably affects both the material acted upon and the agent. The agent that grinds the rock-floor at the bottom of a glacier is also ground. This necessity of work upon both agent and substance acted upon comes under the law of Newton in reference to action and reaction. The fact of work both upon agent and substance upon which the agent acts raises the question as to the distinction between the two. The answer is: The agent is the substance containing energy which it expends in doing work upon other substances. The substance upon which work is done may thereby receive energy, and thus become an agent which does work upon other substances; and so on indefinitely. Indeed, the rule is that one process follows another in the sequence of events, until the energy concerned becomes so dispersed as to be no longer traceable. Theoretically this goes on indefinitely.

Analysis of geological processes.—We have seen that the action of one or more agents through the exertion of force and the expenditure

of energy upon one or more substances is a geological process. It is rare indeed, if it ever happens, that a single agent works through a single force upon a single substance. Commonly two or more agents are doing work by the expenditure of energy of various kinds at the same time upon more than one material. The processes of geology, therefore, vary in their complexity from the action of a single agent through a single force upon a single substance, to the action of all kinds of agents through all classes of force upon the most diverse combinations of substances. Thus the solution by rain-water of pure calcite is a process. Also erosion, which is the work of all the agents by the expenditure of various kinds of energy upon the most diverse combinations of materials, is called a process. It is plain that the number of processes of geology, comprising as they do all possible combinations of energies, agents, and substances, are beyond number, if indeed they are not infinite. If geology is to be simplified, the processes must be analyzed and classified in terms of energies, agents, and results. Each of the classes of energy and agent should be taken up, and the different kinds of work done by it discussed. For instance, the work of the force of gravitation through gases, liquids, and solids should be analyzed. To some extent this has been attempted, but very imperfectly indeed. And such discussion has scarcely been seriously undertaken for the other forms of energy. Text-books should consider each of the classes of energy by itself, the nature of the forces it exerts, the processes through which it works, and the results accomplished through the various kinds of agents.

The general work of each of the agents and the results accomplished should be similarly considered. Not only so, but the work of the different forms that each of the agents takes should be separately treated. Thus, besides considering the work of water generally, the work which it does both running and standing must be treated. The first involves the work of streams; the second, the work of lakes and oceans. This involves the treatment of streams as entities, or, to use a figure of Chamberlin's, as "organisms." The treatment of the work of gases should involve the subjects of gases of the atmosphere, gases of the hydrosphere, and gases of the lithosphere. The treatment of the agents will be more satisfactory in proportion as the work done by each of the forms of each of the agents

is explained under physical and chemical principles in the terms of energy.

It is plain that the treatment of the energies of geology and the treatment of the agencies of geology will overlap, since one cannot be considered without also considering the other; but this is an advantage rather than a disadvantage, for each of the two points of view is very important in enabling the mind to grasp the composite whole. Just as in the science of physics-chemistry it may sometimes be advantageous to consider the subject mainly from the point of view of substance, and at another time mainly from the point of view of energy, and the treatments from both points of view are necessary to build up the science of physics-chemistry; so it is necessary to consider the subject of geology from the points of view of energy and of agent, if an approximation to adequate comprehension be gained.

As already intimated, another point of view from which geology may be considered is the result. This was the chief point of view of the early geological papers and text-books, which were content to tell of phenomena. Phenomena may, and often are, observed and described in advance of their physical-chemical interpretation. But the naming or even the description of the phenomena of the earth without reference to energy or agent is very unsatisfactory. And usually the valuable descriptions of before unobserved phenomena are made in connection with theories of their physical and chemical significance. But it is still true that observation and description present a third important point of view which interlocks with and overlaps the treatment of geology from the points of view of energy and agent.

So complex is the earth that to enable the mind to comprehend the intricately interlocking whole, the subject should be considered from as many points of view as possible. If only the human mind were sufficiently powerful, and means of expression adequate, the ideal method of treatment would be simultaneous consideration and exposition of all possible points of view. But since this method of treatment is an impossibility, we must necessarily at any time consider each portion of the subject in part and treat it in part. The problem is then the selection of the various partial points of view

which are important, and the determination of the order of their consideration.

No one, I think, can hold that any of the points of view above mentioned—process, energy, agent, and result—is unimportant in a general treatment of the subject of geology. It is therefore clear that all these points of view must be handled. There may be difference of opinion as to the order in which they shall be presented; and for different parts of the subject of geology and for different purposes the best order will vary.

We are now in a position to foresee the future development of the science of geology. The early papers and text-books were content to tell of accomplished results. Almost nothing was said with reference to processes. As the science developed, there crept into the literature of the subject more and more reference to processes. The present year a text-book of geology by Chamberlin and Salisbury has appeared, the first which avowedly attempts to treat geology from the point of view of processes rather than phenomena.[1] This is a great step in advance. But a large part of the task of reducing the processes to order in terms of energies, agents, and results still remains to be done. When this is accomplished, we shall have a statement of the principles of geology in terms of physics and chemistry.

How knowledge of processes has developed.—The principles of geology have been developed in the past and will continue to be developed in the future both from the study of processes now in operation and by the consideration of the results of processes which cannot be observed. An excellent illustration of a branch of geology, the principles of which have largely been established by the observation of processes now in operation, is furnished by physiography. So far as one can see, the surface of the land is now being modified by the energies and agents of geology as rapidly as at any time in the past. These energies and agents may have varied in their efficiency from time to time and place to place, but the above statement is broadly true. There are other branches of geology, the principles of which have been mainly developed from results accomplished rather than from observation of the present actions of energies and agents.

[1] Chamberlin and Salisbury, *Geology*, Vol. I, "Processes and Their Results," 1904.

In such branches the probable energies, agents, and processes which produced the observed results were developed from a consideration of the methods by which chemical and physical energy through the agents available could have produced the results observed. For instance, the development of the solar system occurred but once. During that development the earth was formed, including the atmosphere, hydrosphere, and lithosphere. The process of differentiation was not observed by man, cannot be repeated by him. The only method of reaching a probable conclusion as to the manner of accomplishment of the complex result is to consider in what possible ways physical and chemical energy may have acted upon the enormous masses of universe stuff out of which the earth was constructed, and to check this reasoning by the attainable knowledge of what is now occurring upon other heavenly bodies.

The qualitative and quantitative stages of explanation.—The task of explaining geology in terms of processes involving energy and agent has two stages—the qualitative stage and the quantitative stage. For most problems we have as yet been unable to go beyond the qualitative stage. In the qualitative stage of a problem it is shown that a cause is real. In this stage the question is not asked as to how far the explanation applies; *i. e.*, its quantitative importance. Most geologists are content when they reach the qualitative stage. A certain cause is determined to be real in the explanation of certain phenomena. It is then usually assumed that this cause is the only cause. For instance, it has been generally accepted that the loss of heat by the earth results in decreased volume, and that such condensation is a cause for crustal deformation. Many geologists have stopped at this point satisfied. They have not asked the question: To what extent can loss of heat by the earth explain crustal deformation, and are there any other causes which can be assigned? Some years ago I listed a number of causes, each of which partly explains deformation. In addition to secular cooling, they are as follows: volcanism, cementation, change of oblateness of the earth, change of pressure within the earth, change of physical condition of the material of the earth, and loss of water and gas from the interior.[1]

[1] C. R. VAN HISE, "Estimates and Causes of Crustal Shortening," JOURNAL OF GEOLOGY, Vol. VI (1898), pp. 10–64.

Evidently, in order that we may have even an approximately correct idea of the chief causes for crustal deformation, the question must be answered as to the quantitative importance of each of the causes.

The consideration of the processes of geology by quantitative methods is superlatively difficult, yet this task must be undertaken if the science ever approximates certainty of conclusions. This leads to the relations of mathematics to geology. The moment we pass to the quantitative treatment of processes the assistance of mathematics is needed. For simple quantitative calculations arithmetic and algebra may suffice, but for the more difficult problems of geology the assistance of higher mathematics is needed. This, then, raises the question as to whether or not it is expected that the geologist, in addition to knowing physics and chemistry, must also be a mathematician. Undoubtedly this is the ideal equipment of a geologist, which, unfortunately, few if any possess. There are many geologists who apply simple mathematics to various problems. But the man who is so familiar with forces, agents, processes, and phenomena of geology that he is able to handle them, and at the same time is capable of handling higher mathematical reasoning, is rare indeed. Those geologists who have made the attempt to combine mathematical with their geological reasoning usually have shown marked deficiency in their mathematics. Upon the other hand, those mathematicians who have attempted to handle the problems of geology mathematically have usually been so deficient in a knowledge of geology that their work has been of comparatively little value. In view of these unfortunate results, it seems to me that the time has come for co-operation between geologists and mathematicians in the advancement of the science of geology to a quantitative basis. Two or more men should work together, some of them geologists with a broad familiarity with the phenomena and methods of their science, and the others expert mathematicians. In continual consultation, the geologist and mathematician will be able safely to handle the problems of geology quantitatively. This happy condition of co-operation, once reached, will be sure rapidly to advance the science.

The quantitative solution of geological problems is likely to emphasize also another of the principles of geological method of the greatest

importance. The causes offered to explain the phenomena do not exclude one another. It is believed that each of them is a real cause, and partly explains the phenomena—that the different causes are complementary. While a majority of geologists have been content with suggesting a single physical cause for a phenomenon, others have taken more than one possible cause into account. Thus Chamberlin[1] has formally adopted the method of multiple hypotheses. But the great majority of those who have considered more than one hypothesis in connection with a geological problem have carried on their discussions as if one of the suggested causes must be selected to the exclusion of the others.

As a matter of fact, almost every complex geological phenomenon has not a simple, but a composite, explanation. To illustrate, in Chamberlin and Salisbury's text-book of geology it is stated that the explanation of volcanism may be given upon the assumption that the lavas are original; or, second, on the assumption that the lavas are secondary. Under the first assumption it is suggested (1) that lava outflows from a molten interior, and (2) that lavas flow from molten reservoirs. Under the second assumption it is suggested that lavas may be assigned (3) to the reaction of water and air penetrating to hot rocks, (4) to relief of pressure, (5) to melting or crushing, (6) to melting by depression, and (7) to the outflow of deep-seated heat.[2] At the close of the discussion it is said that these hypotheses "must be left to work out their own destiny."[3] I fear many will make the inference, although I have no idea that the authors so intended, that one among these hypotheses will be victorious in the struggle for existence and the others totally overthrown. My point in this connection is that the two main suppositions, and all of the hypotheses under them, may be true in part; that these various explanations are not necessarily exclusive of one another, but may be supplementary. When we have a quantitative discussion of the probable effects which may be expected from each

[1] T. C. Chamberlin, "The Method of Multiple Working Hypotheses," Journal of Geology, Vol. V (1897), pp. 837–48.

[2] Chamberlin and Salisbury, *Geology*, Vol. I, "Processes and Their Results," 1904, pp. 595–602.

[3] *Ibid.*, p. 602.

of the causes suggested, we shall have some idea of their possible relative importance. For my own part I have no doubt whatever that volcanism is to be explained by some combination of the seven causes mentioned, with doubtless other causes which have not yet been suggested, rather than by a single cause. As soon as it is appreciated that to explain a complex phenomenon several causes are usual, if not invariable, rather than exceptional, it becomes plain that their relative importance should be determined, and this can be done only by quantitative methods.

THE INDIVIDUAL PROBLEMS OF GEOLOGY.

Thus far we have been considering the problem of geology as a general one. The subject assigned, "The Problems of Geology," might imply a treatment of the particular problems at present being considered by geologists. For an address this interpretation of the subject is impracticable. Adequately to discuss one of the unsolved problems of geology from the point of view advocated would require a monograph. Not only is it impossible to discuss unsolved problems of geology, but it is impracticable, within the limits of this paper, even to list the problems demanding solution. As evidence of the correctness of this statement it may be noted that a subcommittee of the Carnegie Institution stated scores of problems upon the investigation of rocks, the statement of which, limited to the briefest possible terms, occupies a number of printed pages.[1]

ILLUSTRATIONS OF TREATMENT OF GEOLOGICAL PROBLEMS FROM THE POINT OF VIEW OF ENERGY, AGENT, AND PROCESS.

While it is not practicable to discuss, or even to list, the particular problems of geology, it is possible to mention illustrations of the systematization and simplification of the science by the treatment of processes in terms of energy and agent. These I shall take from my own publications, for the reason that I can more easily give them than any others. My chief subjects of study have been (1) the gross and minor deformations of the lithosphere, and (2) the interior transformations of the rocks, or metamorphism. When I began the study of the first of these subjects, I found a heterogeneous mass of facts in reference to the deformation of many regions, with various guesses

[1] *Carnegie Institution Year-Book*, No. 2, pp. 195–201.

as to how the results came about, but with no consistent attempt to reduce the many observed phenomena to order under the principles of physics and chemistry. The subject of metamorphism was in an even worse condition. The work upon this subject was of the most random character; indeed, nothing short of chaos prevailed. A person who attempted to carry the multitudinous statements of facts in his mind would need more than cyclopedic powers of memory, and the statements would not even have had the artificial order of an encyclopedia. I became convinced that, if the treatment of metamorphism was to continue along the old lines, the subject was doomed to hopeless confusion.

With the above condition of affairs before me, I set about attempting to ascertain the principles which control the various kinds of deformation of rock masses, and which underlay the transformation of rocks. It soon became plain to me that the task was a great problem in applied physics and chemistry. When this was realized, it became clear that it was necessary to know the principles of physics applicable to the deformation of matter and to the alteration of rocks. Thus my first task was to remedy the defects of my basal training by gaining a working knowledge of the well-established principles of these subjects. This task I found a formidable one, which occupied much of my time for several years, and which I can claim to have only very imperfectly accomplished.

In order to understand the diverse phenomena of crustal deformation, it was plainly necessary to know the principles of deformation of small masses, such as can be handled in the laboratory. Unfortunately it was found that this part of the subject of physics is in a very imperfect condition. No systematic statement is available as to the manner in which different substances behave under varying conditions of stress. While studies have been made of the deformation of iron under a moderate range of conditions, comparatively little has been done concerning brittle bodies such as constitute the rocks. Exact knowledge is needed as to the behavior of rocks under the most extreme variations of stress, temperature, amount of water, and other conditions. But while it is highly desirable to have this knowledge, the geologist cannot wait until it is available. The only practicable course is to study closely the phenomena of rock deforma-

tion, and interpret these facts in the light of the physical and chemical knowledge available.

A broad study of the phenomena of deformation by various men showed two classes of very diverse phenomena. In some areas the prominent deformations of the rocks are those of fractures, such as joints, faults, brecciations, etc. In other places the deformations are mainly those of flexure. For instance, in some places one finds that brittle rocks, such as jaspilite and quartzite, are deformed almost wholly by numerous fractures, and in other places have been bent within their own radius, or even minutely and extremely crenulated with no sign of fracture. A close study of the geological conditions under which these two classes of deformation occurred shows that the more modern rocks, which have at no time been very deeply buried, are those which are most likely to exhibit only the effects of rupture; whereas the ancient rocks, and especially those which have been deeply buried, are likely to show the evidence of profound folding without rupture, although often there is superimposed upon the flexures more recent fracture deformation. Physical experiments had shown that, when a brittle substance like a rock is stressed beyond the limit of elasticity under the conditions of the earth's surface, that cohesion is overcome, and rupture takes place. This fact, correlated with the general observation of rupture in recent rocks and those deformed near the surface, led to the conclusion that normally the deformation of the outer part of the earth is by fracture.

After this conclusion was reached, it was a natural step to the conclusion that at a very moderate depth below the surface of the earth the superincumbent pressure is greater than the strength of any rock, and that, if openings could be supposed to exist, they would be closed by pressure; in other words, that the pressure due to the force of gravitation is sufficiently great so that the molecules of the rocks are held within the limits of molecular attraction or are within the limits of the force of cohesion. This naturally led to the suggestion of a deep-seated zone of rock-flowage, in opposition to a zone near the surface, that of fracture. At the time this conclusion was reached, no experiments had been made actually showing the deformation of rocks under the conditions of the deep-seated zone, but since that time Adams and Nicolson have deformed

rocks by flowage in the laboratory.[1] Thus observation of the geologist, inference from the observation, and experimental work have led to advance in the science of physics.

For the present purpose the important thing is to observe that a realization of the very diverse results which follow from deformation under different physical conditions led to a satisfactory classification of two great sets of phenomena which had been noted, but without any reason being assigned why one occurs at one place and the second at another place. Thus in the text-books of geology joints, faults, and folds were described. But there was no attempt to explain why fracture occurred here, folds there, and in a third place both. After it was realized that the great earth-movement makes joints, faults, and other fractures at and near the surface, and at depth, below these structures, other structures which have been called folds, it was possible to reduce the gross deformation of rocks to some systematic order under the principles of physics. There of course remains the working out of the precise physical conditions which result in the various diverse phenomena. For instance, what are the exact conditions of stress which result in the many complex systems of joints? While progress has been made upon this and other problems of gross deformation, a vast amount of work remains to be done before the subject will be even approximately reduced to order in the terms of energy, agent, and process.

It has already been intimated that the subject of rock alteration was in an even more unsatisfactory state than that of gross deformation. The particular alteration of this or that rock was given without any adequate consideration of the geological, physical, or chemical conditions under which the change took place. Thus there were many thousands of descriptions of rock alterations, but no understanding of the reasons why the particular alteration for a given rock found at a given place occurred. To make the matter worse, almost every description of rock alteration was accompanied by vague guesses as to the causes of the changes, the majority of which were little short of grotesque.

[1] F. D. Adams and J. T. Nicolson, "An Experimental Investigation into the Flow of Marble," *Philosophical Transactions of the Royal Society of London*, Series A, Vol. CXCV (1901), pp. 363–401.

After it was appreciated that the gross deformation of rocks is very different in an upper and a deeper zone, the question naturally arose as to whether there are not differences in the rock alterations in these zones. This idea, when followed up, resulted in astonishingly fruitful results. It was found that in the upper zone, that of fracture, the chief alterations which take place are those of oxidation, carbonation, and hydration. These reactions occur with liberation of heat and expansion of volume. In other words, the reactions are controlled by chemical energy. In the lower zone the dominant factor controlling alterations is physical energy. Pressure diminishes the volume. In order to accomplish this, the chemical reactions of the upper zone are reversed. Deoxidation, silication with decarbonation, and dehydration occur with absorption of heat. The reactions controlled by the force of gravitation are under the principles of physics. It thus appears that the reactions of the two zones are opposed throughout. It is plain that if the subject of metamorphism is to be reduced to order, the alteration of the upper zone, that of fracture, must be discriminated from that of the deep-seated zone, that of rock-flowage.[1]

The working out of the principles of metamorphism was a physical-chemical problem. The handling of the problems of rock alteration with fairly satisfactory results was possible because of the rise of physical-chemistry. Had this science not been developed within the past score of years, it would not have been possible to have gone far upon the problem of metamorphism.

It is to be emphasized that gross deformation is not independent of metamorphism, or metamorphism independent of gross deformation; the two interlock. The general solution of the problem of gross

[1] The necessarily narrow limits of this paper render it extremely difficult to show the manner in which the subject of metamorphism has been treated under the system advocated as a general method for geology. By referring to *Monograph XLVII of the United States Geological Survey*, a treatise on metamorphism now just appearing, the reader will better appreciate the illustration. In this volume the forces of metamorphism, the agents of metamorphism, and the zones of metamorphism, are first fully treated, the point of view being mainly physical-chemical. After the general principles contained in these chapters are given, the alterations in each of the different belts and zones are developed. The point of view of the latter chapters is mainly geological, but the geology is interpreted in the terms of the principles earlier formulated.

deformation made it possible to formulate the principles controlling the interior transformations of rocks. In a similar manner these problems interlock with the other problems of physical geology, and physical geology interlocks with the other sides of the subject. The whole science is one interlocking system, a part of which cannot be satisfactorily developed independently of the other parts. For instance, weathering can be placed in order only when considered in connection with general metamorphism, erosion, and sedimentation. Ore deposits can be explained only by combining the principles of volcanism, deformation, metamorphism, etc.

In attempting to reduce a small part of the subject of geology to order under the principles of physics and chemistry, the plan was followed of oscillating between observations of the facts as exhibited in the field and laboratory, and their physical-chemical explanation. After a large number of facts were observed in the light of known principles, the attempt was made better to formulate the principles which explain them. After this was done, the facts were again more comprehensively studied in the field and in the laboratory in the light of the new principles. The statement of principles was then modified and improved by use of the new facts. The improved statement of principles was again tested by further facts. Thus the process of development has been a series of approximations toward both completeness of statement of fact and perfection of formulation of principle, but neither have been attained, nor, so far as we can see, will they ever be reached.

NECESSITY FOR ADVANCE IN THE SCIENCES OF PHYSICS AND CHEMISTRY.

Very often, in the attempt to find principles applicable to the phenomena of deformation and metamorphism, it has been found that the science of physics-chemistry is not sufficiently advanced to make this possible. In such cases physicists and chemists have been asked to develop this subject at the needed points. But at innumerable places the problems have proved to be so numerous and complex that the necessary aid has not been obtainable. Thus there has arisen, with reference to my own work, a great line of unsolved problems which demand the co-operation of physicists and chemists. The same is true of the work of all other geologists interested in the

fundamental problems of geology. As a consequence, when a committee was appointed by the Carnegie Institution to consider what could best be done for the advancement of geology, it was unanimously decided that the most pressing need of the science was, not further support of the study of the phenomena of geology, but the advancement of the principles of physics and chemistry upon which geology is based.[1] In a small way some of the physical and chemical problems, the solution of which are asked by geologists, have been taken up by the Carnegie Institution. Thus the demands of the geologists that their science shall be reduced to order under the principles of physics and chemistry are likely to result in important advances of these sciences.

DEFECTS OF GEOLOGICAL LITERATURE.

If further proof than that already given were needed of the importance of the knowledge by geologists of the basal principles of the elementary sciences, and of their application to geological problems, it is furnished by the literature of geology. It seems to me that the radical defect which pervades the literature of the subject is due to the lack by geologists of such knowledge. Because of this, many geologists are wholly unable to make a logical arrangement of their material, or respectably to discuss the phenomena observed with reference to causes.

Indeed, some geologists seem to take pride in lack of knowledge of principles and of their failure to explain the facts observed in the terms of the elementary sciences. I have heard a man say: "I observe the facts as I find them, unprejudiced by any theory." I regard this statement as not only condemning the work of the man, but the position as an impossible one. No man has ever stated more than a small part of the facts with reference to any area. The geologist must select the facts which he regards of sufficient note to record and describe. But such selection implies theories of their importance and significance. In a given case the problem is therefore reduced to selecting the facts for record, with a broad and deep comprehension of the principles involved, a definite understanding of the rules of the game, an appreciation of what is probable

[1] *Carnegie Institution Year-Book*, No. 1, 1902, No. 2, 1903.

and what is not probable; or else making mere random observations. All agree that the latter alternative is worse than useless, and therefore the only training which can make a geologist safe, even in his observations, is to equip him with such a knowledge of the principles concerned as will make his observations of value.

It is doubtful if more than one or two text-books of geology have been written which do not contain many statements capable of arousing the amusement of the physicist. When the geologists who write the standard books of the science are properly equipped with a working knowledge of the principles of physics and chemistry, the books will cease to be a heterogeneous mass of undigested material mingled with inferences as to the meaning of the phenomena, which to anyone familiar with the principles of physics and chemistry are often ludicrous. From the above point of view, it might be said that the problem of geology, the problem of problems, is to get men who write geological papers and books so well trained in the elements of the sciences upon which geology is based that they shall be able to reason correctly as to physical and chemical causes, and consequently to observe and describe accurately and discriminatingly. It is plain that the geologist who hopes to advance the principles of his science must have a working knowledge of physics and chemistry.[1]

PRINCIPLES OF GEOLOGY THE SAME FOR THE ENTIRE EARTH.

The phenomena of geology for any extensive area—for instance, a continent—are so numerous that, had the science originated in Europe, in America, and in Asia independently, the principles of the science developed in these three regions would have been essentially the same. The chief differences would have been that the emphasis placed upon the different principles would have varied. Also the principles of certain divisions of the subject would have been somewhat more fully developed in one case than in another. For instance, because of differences in the range of latitude and other climatic conditions, certain parts of the principles of physiography would have been more fully developed on one continent than in another.

It is, of course, understood that the foregoing statements premise

[1] C. R. Van Hise, "Training and Work of a Geologist," *Proceedings of the American Academy of Sciences,* Vol. LI (1902), pp. 399–420.

that men of equal ability and attainments had been at work on the problems of geology in the various continents. This supposition is, of course, erroneous, for it is evident that the great constructive work of geology has been done largely by a comparatively few individuals. Indeed, the contrast between nations in the number of creative geologists which they have produced is so great that it is a fair inference that the differences in the principles of the science developed in the three continents under the conditions named would have been more largely due to difference in the capacity of the geologists than to variation in the phenomena demanding explanation. In geology, as in other lines of human endeavor, the exceptional man, the genius, is a factor of paramount importance.

THE PROBLEMS OF PROVINCES AND DISTRICTS.

Thus far we have considered only the development of the principles of geology. They are applicable to the entire earth. There is another great field of geology, which has not yet been suggested—the application of the principles to provinces and districts.

This second line of problems of geology is illustrated by such subjects as the stratigraphy of a given district, its physiography, its paleontology, etc. The working out of the stratigraphy, or physiography, of a given county or township may be of great importance to the inhabitants of that county or township, or even of some consequence to the nation. They are, however, of much less importance to persons interested in the advancement of the principles of geology, unless their elucidation adds to the science some new principle, or some unusually fine illustration of an old principle.

The principles of geology may be broadly comprehended by a single individual. No individual can be familiar with more than a minute fraction of the applications of the principles to the numerous geological provinces of the world. Scarcely a score of years ago it was possible for a geologist not only to know the developed principles of the science, but to know somewhat fully the facts upon which those principles were based. At the present time this is impossible. A man may know the more important facts in reference to a few districts, the broader facts in reference to states, and some of the more general facts in reference to an entire continent, or even more than

one continent; but no man can know more than an inappreciable portion of the geological facts of even the countries which have been somewhat closely studied; and these countries comprise but a small part of the earth.

But it is unnecessary for a man to know all the facts of geology. He need only know the more important facts for a sufficiently broad region so that he may understand the recognized principles of the science, assist in their development, and take part in the discovery of new principles. The discoveries will be found to be largely applicable to the vastly greater regions of the world which are not considered by the discoverer. All this is very fortunate for the science of geology. A student beginning the subject may fully comprehend the truthfulness of many principles which have been developed in various parts of the world through the illustrations furnished by his native parish.

From the foregoing it appears that the geology of the future is to have two aspects, which, as time goes on, will become more and more clearly differentiated: first, the principles of geology; second, the application of principles to various parts of the world.

CONCLUSION.

It is clear that the evolution of the science of geology has followed a strictly natural course. Before the subject was recognized as a science, the earth was being observed. When man turned to nature-study, he began to observe the phenomena exhibited by the earth, such as the stratification of the rocks, and the presence in them of objects which are called fossils. After such observations were made, it was inevitable that sooner or later the question should arise as to the manner in which the results observed were accomplished. Thus the observation of phenomena led to a study of processes. Sands like those observed in a consolidated form were seen in the process of building. The conclusion followed that the consolidated stratified rocks were formed by the processes observed upon the seashore. Sea shells were seen to be produced by animals and to be deposited with the upbuilding sands. This led to the explanation that the fossils in the sedimentary rocks were due to the processes observed.

After a large number of explanations, the methods of which were the same as in the illustrations given, the general doctrine was evolved

that the geological results of the past are to be explained by present processes, or the present is the key to the past. While the above conclusions now seem almost axiomatic, we need not go far back to find them astonishing novelties. So far as we are aware, the natural explanation of fossils was first reached by that amazingly versatile genius, Leonardo da Vinci, in the fifteenth century. The conclusion that the present is the key to the past required for its formulation the intellect of the great Hutton.[1] It was not announced until 1785, and the doctrine was not generally accepted until after Lyell's *Principles* appeared in 1830.

As the science of geology developed, the practice of explaining the phenomena in terms of processes gradually became more common, until, as we have seen, it is dominant in the latest geological text-book. But, as already intimated, the analysis of processes in terms of energy, force, and agent has only begun. It is my belief that at some time in the future a text-book of geology will appear which begins with a discussion of the energies, forces, and agents of geology, the understanding of which is necessary in order adequately to comprehend processes. It has been stated that the problem of geology is the reduction of the science to order under the principles of physics and chemistry. This is equivalent to saying that the problem of geology is the discussion of the subject in terms of energies, forces, agents, processes, and results. Such a discussion will constitute the principles of geology.

It is my deep-seated conviction that by the solution of this problem only can geology be so simplified as to be comprehended with reasonable fulness by the human mind. When this work is done, the broad principles of the science will be capable of statement with

[1] How clearly the great Hutton appreciated the doctrine commonly called that of uniformity is shown by the following quotations from his "Theory of the Earth": "In what follows, therefore, we are to examine the construction of the present earth, in order to understand the natural operations of time past; to acquire principles, by which we may conclude with regard to the future course of things, or judge of those operations, by which a world, so wisely ordered goes into decay; and to learn by what means such a decayed world may be renovated, or the waste of habitable land upon the globe repaired." The concluding sentence of his work is: "The result, therefore, of our present inquiry is, that we find no vestige of a beginning—no prospect of an end."—Charles Hutton, "Theory of the Earth," *Philosophical Transactions of the Royal Society of Edinburgh*, 1785, p. 218; *ibid.*, p. 304.

comparative simplicity and brevity. But so broad and complex is the science of geology that a comprehensive statement of the principles of the entire subject will necessarily be somewhat voluminous.

Supplementary to the principles of geology, which are applicable to the entire earth, there will be a long series of volumes of the geology of different continents, the various political divisions of these continents, the states under those divisions, or even the minor areas, such as counties or townships; for so numerous are the facts of the science that it requires a volume to discuss in detail even a small area. For instance, to give the geology of a township with sufficient fulness to make clear the earth-story there illustrated may require a good-sized volume.

We have seen that geology rests upon physics and chemistry as its foundation; that it is closely related upon one side to astronomy, upon another side to botany; that in its broader sense it includes mineralogy; and that for its satisfactory development the aid of the higher mathematics is needed. It is evident that the man who is to advance geology must be broadly trained in science, and that he have a firm grip upon the nature of energy, ether, and matter, and their interactions.

It is my conviction that when geology is placed in order under the principles of physics and chemistry the science will have passed through a greater revolution than at any previous time in its history.

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GLACIAL AND POST-GLACIAL HISTORY OF THE HUDSON AND CHAMPLAIN VALLEYS. II.[1]

OUTLINE—*Concluded.*

HISTORY.

- Hudson water body and successive positions of ice-edge as it retreated through Hudson Valley.
- Successive positions of the ice-edge in the passages from Hudson to Champlain Valley.
- Successive positions of ice-edge in Champlain Valley.
- Hudson-Champlain water body.
- Higher Glacial Lake Champlain.
  - Erosion of Fort Edward Valley—making upper series of terraces.
- Lake St. Lawrence.
- Marine Champlain.
  - Making lower series of terraces.
  - Extended course of Poultney-Mettawee River.
- Inauguration of present Lake Champlain.
  - Drowning of lower Poultney-Mettawee River Valley.
  - Cutting of outlet of Lake Champlain.
- History in Hudson Valley in Higher Glacial Lake Champlain time and later.
  - Disappearance of Hudson water body.
  - Trenching of old lake- or old sea-floor of Hudson Valley.
  - Origin of Hudson Deeps.
  - Drowning of lower Hudson.
  - Post-Hudson-Champlain changes of drainage in the Hudson Valley.
  - Piracy of Outlet Creek and beheading of Drummond Creek.
- Correlation of Terraces in the Champlain Valley with those in the Hudson Valley.
  - First assumption.
  - Second assumption.
  - Another interpretation.
- Altitude of Hudson water body.
- Origin of Hudson water body.
  - Lake hypothesis.
  - Sea hypothesis.
  - Origin of northward rise of gravel plateaus on each hypothesis for Hudson water body.
  - Origin of submerged channels on each hypothesis for Hudson water body.

[1] Continued from p. 469.

HISTORY.

HUDSON WATER BODY AND SUCCESSIVE POSITIONS OF THE ICE AS IT RETREATED THROUGH THE HUDSON VALLEY.

As the ice retired from the Brooklyn-Perth Amboy moraine northward, it halted for a greater or less time at the successive positions which are marked on the higher lands by belts of thick drift, with more or less distinct morainic topography, by elongate kame areas with the aspect of moraines, often bordered by plains of gravel and sand having the form of overwash or outwash plains, or by aggradation plains without moraine or kame areas at their source. On Staten Island possibly one morainic belt of limited extent, and on Long Island at least two and probably three such morainic belts, mark some of the halting-places of the ice, north of the main moraine. On the Triassic lowlands in New Jersey, no less than seven such positions are marked by belts of thick drift with either the moraine or kame aspect. (See Fig. 8, p. 427.) In the lower ground, both in the lowland west of the Palisade Ridge and in the Hudson Valley, the ice and the ice-waters discharged into a standing body of water. In the low ground, west of the Palisade Ridge, the deposits of the ice-waters are marked by the complex series of sand- and gravel-

plains or plateaus, some of them heading in kames and others with ice-molded but kameless sources, which is found from the latitude of Hackensack and Englewood nearly to the northern border of the state. The deposits of the ice-waters are also marked by the clay which is found underneath the gravel and sand in the southern part of these lowlands, or spread out with little overlying sand or gravel, and which has thicknesses from 100 feet or less, to 215 feet.[1]

That the water body in which these deposits accumulated may have been separated from, and perhaps was slightly higher than the Hudson water body will be shown later (p. 645). It is to be noted that the accumulations marking the successive positions of the ice-edge on the higher land are not traceable across the lowlands occupied by this water body, at least not to the same extent, either in number or continuity, as on the higher land.

In the Hudson Valley the deposits marking the successive positions of the ice-edge do not have notable development south of Sing Sing, but from a little north of this place to north of Glens Falls, and beyond into the Champlain Valley, there is a succession of deposits, described above (pp. 430 ff.), which, it is believed, mark its successive positions. As the ice retreated northward, the ice-front appears to have assumed two distinct phases in different parts of the valley.

Phase 1.—In those parts of the valley (notably the narrower parts) where the gravel plateaus are marked either by morainic phenomena or by irregularities of similar import at the edge next to the Hudson, or by higher elevation next to the Hudson and lower next to the valley wall, and with layers dipping toward the valley wall and southward, it is believed that the ice protruded down the valley, and that the accumulations took place at the edge of this ice-tongue, or between

[1] See *Annual Report* of the State Geologist of New Jersey for 1903, pp. 195–210, and *Final Report*, Vol. V, pp. 506–13, 595–628, 632–42. At the time this report was written three hypotheses were suggested to explain the form of these higher gravel plains and plateaus; namely, (1) that they were accumulated in a water body, either a lake or an arm of the sea; (2) that they had received their form from stagnant ice-masses; (3) that both co-operated. In the absence of wave-wrought features, and in the absence of exposures, the junior author preferred to leave open the question of the origin of these features, where the structure was unknown, although at this time, and for some time before, it had been recognized that a water body existed in the Hudson Valley as the ice was retiring, and that both ice and water body had been influential in producing the forms there found.

the ice-tongue and the valley wall. Such deposits, it is believed, are represented (1) by the terrace south of the Croton River mouth (Fig. 9, No. 20, p. 429); (2) by the moraine on the north slope of the Palisade Ridge, which has not the accompanying gravel plateau (Fig. 9, No. 15); (3) by the Jones Point gravel plateau (Fig. 9, No. 19); (4) by Roye Hook (Fig. 9, No. 29), and possibly that part of the State Camp plateau which appears to slope eastward. In some places where tributary streams head northward the ice occupied the upper portion of the tributary valley at the same time that the ice-tongue existed in the main Hudson near its mouth, so that deposits with layers dipping toward the valley wall contributed from the ice-tongue in the Hudson Valley, occur side by side with deposits from the tributary streams of ice-water which show layers dipping toward the Hudson. The main part of the State Camp plateau, which appears to have been built of materials brought by streams of ice-water down the valley of the Peekskill and its tributaries, is thought to be an example. Other phenomena which indicate the presence of the ice in the valley, against which stratified drift was accumulating at higher levels, but to which this valley ice was not active in contributing, it is thought, may be represented by the deposits at Carthage Landing and Low Point (Fig. 9, No. 44), and at New Hamburg (Fig. 9, No. 46). At the latter place, however, the waters from the ice in the valley may have been active contributors in building the plateau, at least in its early stages. (5) The West Point gravel plateau, and probably the Cold Spring kames and the Cold Spring-Garrisons terrace (Fig. 9, Nos. 31, 33) also represent deposits made at the edge of a tongue of ice which occupied the valley.

Phase 2.—The second phase of the ice-front is represented in the broader parts of the lower Hudson and in the broad upper Hudson where the gravel plateaus are marked by moraines or kames or undulatory topography of similar import, at the margin toward the valley walls, and by the smoother surface and steep outer face toward the Hudson, together with the dip of the layers generally away from the valley wall, and the gradation of the materials down the dip from coarse gravel into sand and finally into clay. This clay spreads out in the upper Hudson as a wide plain, rising gradually from the present Hudson River bluffs toward the gravel plateaus and the valley

walls. In these parts of the Hudson it is believed that an embayment in the ice-front existed in the deeper water over the lower parts of the plain, and that the ice-edge is marked (1) by the series of gravel plateaus with the characters above mentioned at their upper margin; (2) by the kames fronted by clay-plains without intervening gravel plateaus; and (3) by the series of elongate depressions like those between the plateaus of the series south of Saratoga Springs now occupied in part by lakes, such as Round Lake and Saratoga Lake, Lonely Lake, and perhaps also Ballston Lake.[1]

Such a form of the ice-front is marked, it is believed, by the deposits (1) at Croton and Croton Landing, and at Haverstraw and North Haverstraw (Fig. 9, Nos. 22, 15, and 17); (2) at Newburg-New Windsor, and Fishkill-Dutchess Junction (Fig. 9, Nos. 37, 38, and 42, 41). Other places where the ice halted are marked (1) by the South Schodack gravel plateau (Fig. 13, No. 73, p. 436) and the line of kames extending northwest of East Greenbush (Fig. 13, No. 74), by kames near Teller Hill, and the line extending through North Albany to Newtonville (Fig. 13, No. 65), (2) by the South Bethlehem gravel plateau (Fig. 13, No. 62); (3) by kames near New Scotland and Voorheesville (Fig. 13, Nos. 63 and 64); (4) by the Troy gravel plateau and kames (Fig. 13, No. 76); (5) by the series of gravel plateaus separated by elongate depressions, south of Saratoga Springs, where several successive positions of the ice-edge are marked; (6) by the succession of kames and gravel plateaus near Glens Falls, where several positions of the ice-edge are marked (Fig. 13, No. 85, and Fig. 18, west of No. 86, and Nos. 87 to 89, p. 454). This includes the Glen Lake kame area north of Glens Falls.

The depth of water into which the ice flowed and built up kame areas and similar deposits appears in places to have been considerable, as much as 60 to 80, or possibly 100 feet, if the evidence furnished by the Teller Hill kames, southeast of Albany (elevation of top, 280 feet) and the adjacent South Schodack-East Greenbush gravel plateau (elevation, 340–360 feet) be correctly interpreted. The 260–280-foot Lonely Lake gravel plateau (Fig. 13, No. 83) was built in water

[1] The writer does not mean to imply here that the plateaus between these depressions were built only from successive positions marked by the depressions, for probably the building was in process during the retreat from one depression to the next succeeding.

which was 100 feet deep over the plateau, if the adjacent plateaus be correctly interpreted. These figures are in accord with those showing the depth of water in which the ice succeeded in making a subdued moraine in the basin of Lake Passaic. They do not show the total depth of water in the water body, but the depth only in which the ice was able to build the moraine, kames, etc., mentioned. If the proportion of ice to débris carried were known, it would furnish a means of estimating the thickness of the ice on these moraines and kames.

In the Hudson Valley no less than fifteen halting-places are thus indicated, and of these at least six are marked by distinct morainic phenomena. This does not take account of the area between Poughkeepsie and Catskill, which was observed only in transit.

SUCCESSIVE POSITIONS OF THE ICE-EDGE IN THE PASSAGES FROM HUDSON TO CHAMPLAIN VALLEY.

The successive positions of the ice as it retreated from the Hudson Valley into the Lake Champlain region are not known. In the western or Lake George passage, after having built the Glen Lake-Hopkins Pond kame area (Fig. 18, Nos. 87–89), thus forming the dam that blocks the valley and makes the basin in which southern Lake George is situated, the ice is not known to have made notable deposits until the northern end of Lake George is reached, where the western passage opens out into the Lake Champlain Valley. In the eastern passage the successive positions of the ice-edge are not known. It seems probable, however, that the ice-front had a direction such that local lakes were formed in tributary valleys in which clays similar to those of the Hudson and Champlain regions were deposited, but at levels higher than those reached by the Hudson water body.

SUCCESSIVE POSITIONS OF ICE-EDGE IN CHAMPLAIN VALLEY.

The successive positions of the ice in the Lake Champlain Valley are not well known. Some of its positions are marked by the terraces: (1) at Baldwin and northward (Fig. 18, No. 105, *A*, p. 455); (2) at Street Road (Fig. 18, No. 107) and northward; (3) by the moraine northwest of Crown Point (Fig. 18, northwest of No. 108); (4) by limited gravel areas along the mountain-side from Port Henry

to Westport; (5) by the Bouquet River high-level delta; (6) by the Reber and Towers Forge gravel plateaus or deltas on the North Branch of the Bouquet River; (7) by the moraine or series of moraines along the higher land between Harkness and Schuyler's Falls, and at Cadyville and west toward Dannemorra; (8) by the Saranac high-level gravel plateau; (9) by kames or moraine west by south of West Chazy.

HUDSON-CHAMPLAIN WATER BODY.

When the ice had retreated into the Champlain Valley, the Hudson water body occupied the lowland between the Hudson and the Lake Champlain Valley also, and may now be conveniently referred to as the Hudson-Champlain water body (see Fig. 22).[1] The successive positions of the ice as it retreated up the Champlain Valley are known to the writer at a few points only, and these are on the west side of the valley. The moraines found above the highest level reached by the water body near Crown Point, and at the various places indicated in the detailed description above (pp. 462, 463), between Harkness Station and Cadyville, and west of the latter place toward Dannemorra, all indicate a general north-south and northeast-southwest direction of the ice-front, and also indicate that the ice was in the lower land and its edge was on the slopes of the higher land. This appears likewise to have been true when the Baldwin and Street Road plateaus were built. Where the ice-edge and the body of ice were at Crown Point when the highest deposits of lacustrine origin were deposited is not known, although doubtless, it could be determined by detailed investigation. It seems difficult to reconcile the eastward dip of the stratified drift built out in the water body with the position of the body of the ice in the lowlands when the moraine higher on the mountain-side was built. The deltas, both on the main Bouquet River and on the north branch, are so situated that neither the assumption of an embayment in the ice-front nor a protruding tongue of ice down the Champlain Valley is necessary to explain the phenomena. The deposits of gravel at 580 feet on the Ausable may be interpreted

[1] This name was first given to the water body occupying the Hudson and Champlain Valleys by MR. WARREN UPHAM, who published on this subject in 1891 in the *Bulletin of the Geological Society of America*, Vol. III, pp. 484–87, and in the *American Journal of Science*, Vol. CXXIX (1895), pp. 13 ff.

FIG. 22. FIG. 23. FIG. 24.

FIG. 22.—Approximate area once covered by the Hudson-Champlain water body on the assumption that it was a lake. The outline does not include the highest levels reached as the ice was retreating from the Brooklyn-Perth Amboy moraine to Kill van Kull, nor does it include the extension of the area into Long Island Sound.

FIG. 23.—Approximate area once covered by Higher Glacial Lake Champlain. No attempt is made to show the northern limit.

FIG. 24.—Approximate area covered by "Marine" Champlain. No attempt is made to show the northern limits reached by these waters.

with either form of front. The highest Saranac gravel plateau indicates the presence of the ice at its northern margin, and possibly some of the phenomena of the western margin indicate its presence there, but this plateau is not well known. It will be referred to again.

On the whole, then, the moraines of the west side of the Champlain Valley, at high levels, indicate a retreat of the ice with a general north-south or northeast-southwest front, and with the body of the ice in the valley. At lower levels, in general, no embayment in the ice-front seems to be required by the gravel plateaus, although deposition of some of the stratified drift in the water body is difficult to understand if the ice occupied the lowlands, and there was no embayment. The high-level Saranac gravel plateau or delta is probably an example. It seems necessary to believe that when the moraines at high levels near Harkness and west of Cadyville were being built local lakes existed at the front of the ice in the valleys of streams now flowing into Lake Champlain, at levels higher than the level of the water body in the Champlain Valley.

HIGHER GLACIAL LAKE CHAMPLAIN.

As the ice retreated through the Champlain Valley, an uplift took place at the south which separated the water body in this valley from the Hudson water body south of Fort Edward and inaugurated the history of a water body which Baldwin first named Glacial Lake Champlain. In view of the fact that another glacial lake may be represented by the upper part of the lower series of terraces, it seems best to call it Higher Glacial Lake Champlain. This lake drained southward through the Fort Edward Valley and across the barrier south of Fort Edward. Whether the Hudson water body continued to exist for any length of time after the inauguration of Higher Glacial Lake Champlain is not known. Indeed, it is not known that its disappearance may not have been on the appearance of Higher Glacial Lake Champlain. By this time, or earlier, those peculiar conditions which it appears had existed through much of the history of the Hudson water body, and had prevented the making of distinct wave-wrought features, ceased to be effective, and the upper series of wave-wrought features, which may be seen from Street Road north,

was made. Contemporaneously with at least the lower terraces of this upper series, the Fort Edward outlet valley was eroded. The question as to where the ice-edge was when Higher Glacial Lake Champlain was inaugurated will be referred to presently, as will also the greater range of the upper series of wave-wrought features from Street Road to north of Crown Point. When the lowest terrace of the upper series was made, the water-level remained constant long enough for a delta to be built on a number of the northern streams. These deltas are capable of another interpretation, however, as will be seen later.

LAKE ST. LAWRENCE.

After the upper series of terraces had been completed, the Fort Edward outlet was abandoned, and the water-level fell rapidly to the upper terrace of the lower series. Whether this level was the sea-level or not seems uncertain. The level of the marine fossils falls below it 70–80 feet at the north, and not far from that amount at the south, so far as the writer has been able to discover.[1] If this water-level, represented by the upper terrace of the lower series, was not the sea-level, then it represents a lake-level made by the opening up of some outlet, presumably toward the St. Lawrence, which was lower than the Fort Edward outlet. The location of such an outlet is entirely unknown, and its existence is hypothetical. In 1895 Mr. Warren Upham suggested such a lake "occupying an area from Lake Ontario to near Quebec," and "dating from the confluence of Lakes Iroquois and Hudson-Champlain." Concerning it he says:

> From the time of union of Lakes Iroquois and Hudson-Champlain a strait at first about 150 feet deep, but later probably diminishing on account of the rise of the land about 50 feet, joined the broad exposure of water in the Ontario basin with the larger expanse in the St. Lawrence and Ottawa valleys and the basin of Lake Champlain. At the subsequent time of ingress of the sea past Quebec the level of Lake St. Lawrence fell probably 50 feet or less to the ocean level. The place of the glacial lake so far west as the Thousand Islands was then taken by the sea.

As thus defined, Lake St. Lawrence would fall in with the non-fossiliferous part of the lower series of terraces in the Champlain region. It is to be noted, however, that these terraces do not belong

[1] If fossils occur up to 250 feet, south of Vergennes, as reported by early investigators, the above does not hold.

to the Hudson-Champlain water body, nor even to the Higher Glacial Lake Champlain water body, but were made after the abandonment of the Fort Edward outlet. In 1903 Mr. Upham referred the low-level delta of the Hudson at Fort Edward and certain high-level terraces in Chesterfield in the Champlain region to Lake St. Lawrence. As will be seen from the foregoing account of the history of this region, the present writer considers this low-level delta at Fort Edward as having been made either in the latest stage of the Hudson-Champlain water body or in the earliest stage of Higher Glacial Lake Champlain, and the high-level terraces in the northern part of the Champlain region as having been made in Higher Glacial Lake Champlain. If the non-fossiliferous levels in the lower series of terraces in the Lake Champlain region be referred to Lake St. Lawrence, the Fort Edward delta and the high-level terraces in the northern Lake Champlain region cannot be so referred. Since it is doubtful if the water body in which either the high-level terraces or the Fort Edward delta were made reached to the St. Lawrence, it would seem to be inappropriate to call it Lake St. Lawrence. Altogether it seems best to reserve this name for the hypothetical lake which followed the union of the water bodies in the Ontario and Lake Champlain regions, as originally defined by Upham.

MARINE CHAMPLAIN.

If the upper terrace of the lower series represents the sea-level, then, on the abandonment of the Fort Edward outlet, the history of the Higher Glacial Lake Champlain was closed and that of Marine Champlain was inaugurated. If during the fall of Higher Glacial Lake Champlain level to the upper terrace of the lower series there was no change in the altitude of the land, then, since the difference in level between the two series is generally 120 feet, Higher Glacial Lake Champlain must have been at its closing stage 120 feet above sea-level, and at its higher stage, barring uplift during its history, it must have been at least 75–100 feet higher. If the upper terrace of the lower series of terraces does not represent the sea-level, but does represent a lake-level, then Higher Glacial Lake Champlain was more than 120 feet A. T. when its outlet was abandoned. It is to be noted that the level of the Fort Edward outlet valley at White-

hall is close to 120 feet A. T., and if Higher Glacial Lake Champlain at the close of its history was 120 feet above sea-level, then there has been no change in level in this part of the outlet since that time, but farther south, at the 160-foot divide near Fort Edward, there has been an uplift of more than 40 feet.

During Marine Champlain time the lower series of terraces was made in the Champlain region from the uppermost marine level down to near the present Lake Champlain levels. Since the uppermost terrace of the lower series, when projected southward, falls below the Fort Edward outlet level, and since marine fossils have not been found south of Port Henry, where they were found at a level of 140 feet and lower, it is believed that the sea did not reach south as far as the Hudson Valley. It has been calculated, by projecting the terrace gradient southward, that Benson Landing or Putnam Station was approximately the southern limit reached by the waters forming the upper terrace of the lower series. During the time in which the lower series of terraces was being made, which it will be convenient to refer to as "Marine" Champlain[1] time, uplift was taking place, greater at the north than at the south, thus producing a wider range of the lower series of terraces at the north than at the south.

EXTENDED COURSE OF POULTNEY-METTAWEE RIVER.

While the waters of the south end of "Marine" Champlain were receding northward on account of the uplift of the land, or at first on account of the cutting of the outlet of Lake St. Lawrence, if "Marine" Champlain includes lake terraces, and later on account of the uplift of the land, the streams which had flowed into Higher Glacial Lake Champlain, and which, because of the sudden fall of its water-level, had extended their courses across the old lake-floor plain to the new shore, finally were extending their courses across the old sea-floor to the receding shore. This was true of the Poultney and Mettawee Rivers, which during Hudson-Champlain and Higher Glacial Lake Champlain time debouched into that water body by independent mouths (see Fig. 25, *A*). On the fall of Higher Glacial Lake Champlain to "Marine" Champlain they became united and with other formerly independent

[1] "Marine" Champlain levels would thus include both those of the hypothetical Lake St. Lawrence and the levels marked by marine fossils, which are called Marine Champlain levels (without the quotation marks).

streams extended their courses across the newly exposed lake-floor from near Whitehall to the new water-level, which was, perhaps, somewhere near Putnam Station. The main stream of these united streams is referred to as the Poultney-Mettawee River (see Fig. 25, *B*). As the "marine" water body gradually withdrew, this stream extended its course to the new levels, and finally at the close of Marine Champlain time, on the inauguration of present Lake Champlain, it had its mouth some five miles northeast of Port Henry (Fig. 25, *C*, *E*) where, apparently, it built out a delta which is now about 23–51

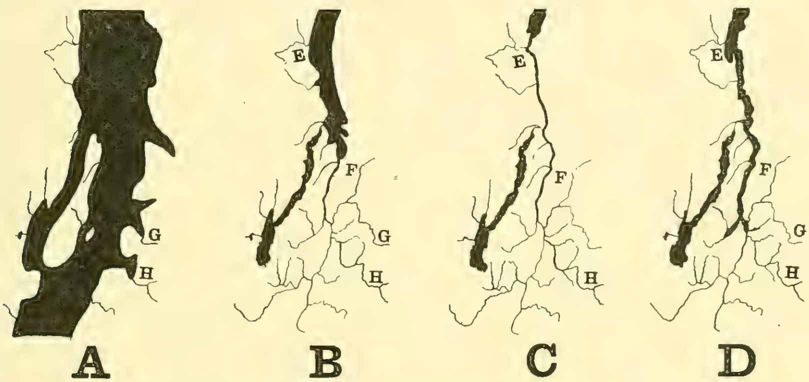

FIG. 25.—Changes in the Poultney-Mettawee River System.

A, the system dissevered in Hudson-Champlain time; *B*, the united and extended courses of the Poultney and Mettawee Rivers and their tributaries at the beginning of "Marine" Champlain time; *C*, the same at the close of "Marine" Champlain time or on the inauguration of present Lake Champlain; *D*, the Poultney-Mettawee system dissevered by the tipping of the water of Lake Champlain into the southern end of its basin caused by differential northern uplift; *E*, Port Henry; *F*, Benson Landing and Putnam Station; *G*, Poultney River; *H*, Mettawee River.

feet above sea-level or 50–78 feet below lake-level (Fig. 20, p. 467). During "Marine" Champlain time this stream cut out the channel in the clay plain described above (pp. 466–68) fromWhitehall to Benson Landing and northward to beyond Port Henry. Deposits made by the stream at successive positions of its advancing terminus, other than the submerged delta, have not been recognized, but they are in large part beneath the waters of the lake. The earlier deposits, however, should be found at low levels north of Benson Landing.

INAUGURATION OF PRESENT LAKE CHAMPLAIN.

The emergence from the sea of the barrier which makes present Lake Champlain, closed Marine Champlain history and inaugurated

present Lake Champlain. By greater northern uplift Lake Champlain has been warped into the southern part of its basin, thus submerging the lower Poultney-Mettawee Valley, dissevering its system, and drowning the lower courses of its tributaries, including the South Bay Creek, and numerous other streams in southern Champlain (see Fig. 25, *D*, Fig. 20, and Fig. 21).

The streams in northern Champlain did not have their courses extended because of the uplift, for the outlet at the north controlled the water-level. Their courses have been extended only by the lowering of the water-level because of the cutting down of the outlet—an amount which Baldwin[1] has placed at 50 feet, but concerning which the writer has made no observations. Terraces lower than those of Marine Champlain have been made in present Lake Champlain and exposed to view by the lowering of the water-level due to the cutting of the outlet.

With this uplift, greater at the north than at the south, came the revival of north-heading streams and the arrest in the development of south-heading streams—a process which seems, from the topographic maps, to be well shown by East Creek, and by Dead Creek and its south-heading tributaries. Revival seems to be shown by the north-heading tributaries of Dead Creek.

The rapid down-cutting of the Poultney-Mettawee River, because of its steep northward gradient (120 feet in 14 miles, if the estimates of elevations at the close of Marine Champlain time be correct) surpassed that of most of its tributaries, which had neither the advantage of the steep northward gradient (since most of them had either an eastward or westward flow), nor had they the advantage of the volume of water of the larger stream. Consequently these tributaries were left to descend over steep slopes into the valley of the main stream (see Fig. 16, *A*, p. 452). The larger tributaries have been able to push this steep part of their gradient farther back from the main stream than the smaller ones. South-heading tributaries, with the advantage of the steep gradient given by the attitude of the land when the Poultney-Mettawee was cutting its channel, were more successful in keeping pace with the cutting of their mains, but since the northern uplift they have been arrested in the continuance

[1] *American Geologist*, Vol. XIII (1894), p. 104.

of this work, while north-heading tributaries have been given the advantage. It is believed that on some of the streams this record can be read from the topographic maps.

HISTORY IN HUDSON VALLEY IN HIGHER GLACIAL LAKE CHAMPLAIN TIME AND LATER.

The history of the Hudson Valley has been left at the point where the southern uplift brought a barrier south of Fort Edward into effective position and inaugurated Higher Glacial Lake Champlain (see Fig. 23). How long the Hudson water body survived is not known. It is not known, indeed, that its history overlaps to any extent the history of Higher Glacial Lake Champlain. The uplift which produced the latter may have been the final cause for the disappearance of the former. If the Hudson water body survived long after the inauguration of Higher Glacial Lake Champlain, then deposits made by the outlet stream from that lake would be expected at the point where it debouched into the Hudson water body. They may be present, but the region where they would be expected has not been studied enough to determine this point. Some stages in the lowering of the Hudson water body are represented by the low-level deltas mentioned at South Bethlehem, on the Hoosick River, on the Batten Kill, on the Hudson River, and possibly on other streams. It is a question whether any of these fall within Higher Glacial Lake Champlain time. Possibly the 280–300-foot Hudson River delta between Glens Falls and Fort Edward does. If neither this nor the Oniskethau low-level delta at South Bethlehem falls within that time, then certainly the Hudson water body had been reduced to a very shallow representative of its former extent, for the latter delta is only 20–40 feet higher than the lowest part of the floor opposite this place.

Whatever may have been the history soon after the inauguration of Higher Glacial Lake Champlain, it is certain that long before the close of that history the Hudson water body had disappeared, and that the outlet stream of Higher Glacial Lake Champlain, the greater part of which flowed through the present Hudson River valley (see Fig. 23), had taken its course across the old floor of the Hudson water body, that the streams which had debouched into the

Hudson water body had extended their courses across its old floor to the main stream flowing through the bottom of the trough made by the meeting of the slopes of the old floor. Into this old floor the outlet stream of Higher Glacial Lake Champlain trenched its course at a rate so rapid that the tributary streams were unable to keep pace with it, and they were thus made to descend to their main over steep slopes, which the small streams have not yet succeeded in pushing back far from the present Hudson bluffs (see Fig. 16, *A*).

Where the mouth of the Hudson was at this time is a subject for discussion, but it is certain that the land was higher than now and that the Hudson, at least in those regions where it is bordered by clay plain, cut its channel to depths now covered by the waters of the Hudson estuary 10–50 feet deep north of Catskill. Just how deep the cutting of this channel in the lower Hudson was during Higher Glacial Lake Champlain time is a matter of less certainty for two reasons: First, because there has been subsequent filling, as shown by at least 25 feet of clay at Croton, which contains "flags" and shells, while the clay below does not contain them, as reported by the dredgers excavating clay from the river for brick-making; second, because of the occurrence of certain "deeps," the origin of which is a matter of discussion. Such deeps are the New Hamburg "deep" (120 feet), the West Point deep (216 feet), Stony Point-Verplanck's Point deep (102 feet), Fort Washington deep (155 feet), and others. These deeps may be due either to scouring[1] by the Hudson during Higher Glacial Lake Champlain time or by the tide since then, or they were original depressions bridged by buried masses of stagnant ice over which the large amount of clay eroded from the upper Hudson during Higher Glacial Lake Champlain time was carried to the sea. If such ice-bridges existed, the deposition of materials carried by the waters of the stream would not be necessary. Subsequent melting of the ice would leave the "deeps."

While the origin of these deeps is open to discussion, on the whole it seems certain that the Hudson had cut its channel to a considerable depth below present sea-level before the close of Higher Glacial Lake Champlain time. This necessitates an altitude of the land at that time higher by the amount of the general cutting, at least.

[1] For ability of a stream to scour its channel below sea-level see CHAMBERLIN AND SALISBURY'S *Geology*, Vol. I, pp. 162 and 184.

In the process of down-cutting the river terraces which occur in the upper Hudson and on the tributary streams in both upper and lower Hudson, were made. Some river terraces had also been made in the tributary valleys before the close of the history of the Hudson water body.

Before the close of Higher Glacial Lake Champlain history, it is believed, the depression which has drowned the lower Hudson and its tributaries had begun. The basis of this belief is the amount of filling of the southern Hudson since the submergence. While this is a matter subject to revision on more accurate knowledge, calculations made indicate that the contributions of the Hudson and its tributaries since the submergence would be inadequate to furnish the material for this filling, and therefore that some of it was supplied by the cutting of the trench in the old lake-floor or old sea-floor in the northern Hudson Valley, before the Fort Edward outlet was abandoned.

POST-HUDSON-CHAMPLAIN CHANGES OF DRAINAGE IN THE HUDSON VALLEY.

By the close of Higher Glacial Lake Champlain history nearly all the cutting by the Hudson south of Fort Edward had been accomplished. This is shown by the fact that the Fort Edward outlet floor is within less than 20 feet of the present Hudson level.

Aside from the trenching of the consequent courses of the streams below the floor of the Hudson water body, the pushing back of the steep gradients from the neighborhood of the Hudson River bluffs, and the development of subsequent tributaries on the consequent streams, a part of which at least was accomplished in Higher Glacial Lake Champlain time, there have been few changes in the valleys of the small streams since the disappearance of the Hudson water body. Depression of the land, part of which probably took place before the close of Higher Glacial Lake Champlain time, has drowned the lower courses of many tributaries from Troy south, and gravel has been carried out from the higher land into the trenches in the clay, making, in some cases, a gravel-floor, and in others, by further erosion, a gravel-floor and gravel-capped clay terraces, as on the Oniskethau. In a few places it seems likely that readjustments in drainage have taken

place because of the competition of neighboring streams. This seems to be true of the relations between Drummond Creek, a tributary of Saratoga Lake, and Outlet Creek, the outlet of Ballston Lake, which flows into Round Lake from the west (see Fig. 26).

Piracy of Outlet Creek and beheading of Drummond Creek.—Drummond Creek flows northeastward into Saratoga Lake through a rather broad, flat-bottomed valley, which is the northeastern part of one of the depressions between gravel plateaus south of Saratoga. Although this depression extends southwest beyond Ballston Lake, its southwestern part, including Ballston Lake, is not drained through Drummond Creek,

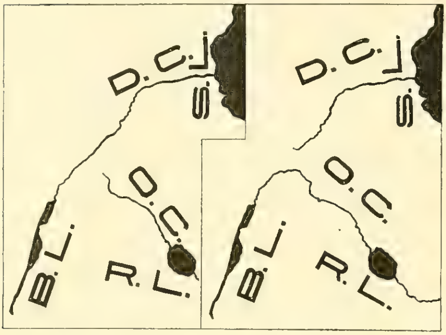

FIG. 26.—Piracy of Outlet Creek.

O. C.=Outlet Creek; D. C.=Drummond Creek; B. L.=Ballston Lake; R. L.=Round Lake; S. L.=Saratoga Lake.

but by a stream called Outlet Creek, flowing from Ballston Lake northeastward to a point a little over a mile from the lake near a place named East Line, where it makes a sharp turn southeastward and descends through a narrow, steep-sided valley with a high gradient to Round Lake (188 feet in altitude). At the point where Outlet Creek makes its southeastward turn its floor is something less than 280 feet in altitude. The question whether Drummond Creek has been beheaded by the working back of Outlet Creek, which tapped it and thus diverted its waters into Round Lake, would seem to rest upon the question whether Ballston Lake, which is now 285 feet above the sea, was ever enough higher to drain over the divide at 300 feet, down Drummond Creek into Saratoga Lake.

CORRELATION OF TERRACES IN THE CHAMPLAIN VALLEY WITH THOSE IN THE HUDSON VALLEY.

In the description of the wave-wrought terraces of the Lake Champlain region mention was made of the fact that in the upper series of terraces there is a range from the highest to the lowest of

about 200–220 feet at Street Road and Crown Point. This great range extends north of the latter point, but not so far north as the Bouquet River. From this river northward the range is from 75 to 100 feet, apparently increasing from south to north. The question arises at once: What is the explanation of the greater range of wave-wrought features at Street Road and Crown Point? Were they produced wholly in Higher Glacial Lake Champlain, or are part of them due to wave-action in the preceding Hudson-Champlain water body before the inauguration of Higher Glacial Lake Champlain? The decision of these questions depends on the correlation of the terraces in the Champlain Valley and the water-levels represented in the Hudson Valley. Since terraces have not been found in the narrow east and west passages which would connect the levels in the Hudson and Champlain regions, the possible correlation of the terraces in these regions must be covered by a series of assumptions which shall include the range of probable fact.

First assumption.—If the making of the gravel plateaus at Street Road and Crown Point be correlated with the emergence of the barrier at the south of the Fort Edward outlet, then the wave-wrought terraces of the upper series all fall within the history of Higher Glacial Lake Champlain and the greater range here might be due to the cutting down of the outlet and consequent fall of water-level, before the ice had retired far enough north to permit the making of these terraces in the northern Champlain valley. If this be the true explanation, it would require a total cutting of the Fort Edward outlet of 200–220 feet, during Higher Glacial Lake Champlain history, which is greater by 60–80 feet than any possible barrier which the present topography will permit. The second hypothesis to account for the greater range of wave-wrought terraces in southern Champlain, on the assumption that they were all made in the Higher Glacial Lake Champlain water body, is that during the history of this water body there were not only the conditions mentioned in hypothesis 1, but there was also a warping upward of this particular portion of the basin, in excess of the up-warping at the outlet, so as to produce the extra spread of terraces. On the most favorable assumption as to the original height of the barrier south of Fort Edward, this would require no less than 60–80 feet of up-warping at Street Road and Crown Point in excess of that at the outlet.

The emergence of the barrier assumed in this correlation requires a fall of the Hudson-Champlain water-level of 120 to 160 feet, while the ice was retiring from the neighborhood of the barrier south of Fort Edward to Street Road and Crown Point. If the Hudson-Champlain water body was an arm of the sea, this fall of water-level was due to uplift. The time necessary to produce this uplift was sufficient to permit the making of at least one secondary delta near Glens Falls on the Hudson—the 340-foot delta, and perhaps a second—the 280–300-foot delta east of the latter (see Fig. 18, p. 455). It is possible, however, that the 280–300-foot delta was made in the Higher Glacial Lake Champlain water body. It is a question whether this length of time was not more than that required for the ice to retreat to Street Road and Crown Point, and to make any deposits that are known between the deposits in the vicinity of Glens Falls and these points. If the time for the ice to retreat from its position near Glens Falls to Street Road is indicated by the time necessary to make the two secondary deltas of the Hudson River, it would seem that the ice retreat was excessively slow. If, on the other hand, the rate of retreat was similar to that in the lower Hudson, it would seem that the rate of uplift was excessive. There are, however, some indications that the history between the making of the glacial deposits in the vicinity of Glens Falls and those at Street Road and Crown Point was somewhat complicated, and, if so, there may have been time for the uplift mentioned during this history. If the Hudson-Champlain water body was a lake, the fall of the water-level which preceded the emergence of the barrier south of Fort Edward was in part due to the cutting of the Brooklyn Narrows outlet. The full amount of the cutting of this outlet, so far as known, is only 122 feet. If this be distributed among the sixteen or more halting-places between Brooklyn and Street Road, it would produce but a few feet of fall during the time of the retreat of the ice from the barrier south of Fort Edward to Street Road and Crown Point. Even if allowance be made for the increase in rate of cutting of the Narrows outlet on the accession of the waters of Lake Iroquois through the Rome outlet, the lowering of the water-level from this cause, while the ice was retreating from the barrier south of Fort Edward to Street Road, can have been only a small part of the total change in water-level produced by the

cutting of the Narrows outlet. It would therefore follow that a large part of the 120–160-foot fall of water-level required in order to permit the emergence of the barrier south of Fort Edward was due to uplift, and the above remarks concerning the rate of the uplift and of the ice retreat would apply.

The correlation above assumed has the advantage of being in accord with the facts which suggest the existence of a Higher Glacial Lake George during the retreat of the ice from north of Glens Falls to near Street Road, and the disadvantage of permitting the formation of wave-wrought terraces at Street Road and Crown Point in Higher Glacial Lake Champlain in the approximate neighborhood of the ice under conditions which are cited below as causes preventing the formation of such terraces in the Hudson-Champlain water body.

Second assumption.—If the upper levels at Street Road and Crown Point be correlated with levels above the barrier south of Fort Edward, then the Street Road gravel plateau, the Crown Point high-level deposits, and a part of the upper series of wave-wrought terraces at these places were formed in the Hudson-Champlain water body. The absence in northern Champlain of the upper levels in the upper series of these wave-wrought terraces may be ascribed to the presence of ice here while they were being formed in southern Champlain. Under this assumption the demands made by the post-Higher Glacial Lake Champlain uplift at Street Road and Crown Point, will possibly permit the correlation (1) of the highest Street Road terrace with the 389-foot Glens Falls level, and (2) certainly with the 340-foot level. If the first correlation be correct, it is fatal to the hypothetical Higher Glacial Lake George; or if the Higher Glacial Lake George be real and not hypothetical, then its existence is fatal to the first correlation, and probably also to the correlation of the 340-foot Glens Falls delta with the Street Road and Crown Point levels, although it is barely possible that the latter correlation is permissible, even though the Higher Glacial Lake George did exist. If some terraces of the upper series at Street Road and Crown Point be thus assigned to the action of the Hudson-Champlain waters, then it follows that when Higher Glacial Lake Champlain was inaugurated the ice was as far south as the delta of the Bouquet River, where the

great range of the upper series of terraces has not been found. But if the ice was present on the Bouquet River when Higher Glacial Lake Champlain was inaugurated, there was time for the cutting down of the outlet as it retreated northward, and thus it would be expected that the terraces at the Bouquet River would have a greater range than northward where the uppermost wave-wrought terrace was not made until after the uppermost Bouquet terrace was completed. The failure of the terraces to show a greater range at this point (latitude of the delta on the Bouquet River) than farther north would indicate, either that the outlet was being cut very slowly, or that the water-level was being maintained at the north in some way, as the ice retreated from the Bouquet deltas. It is possible that uplift of the outlet maintained the water-level, or even caused it to rise in the northern part of the basin as the ice retreated, thus causing as great a range of terraces farther north as on the Bouquet River. The fact that the upper wave-wrought terrace near Whallonsburg is 30 feet higher than the surface of the Bouquet deltas would suggest that this tipping northward had been more than sufficient to overcome the effect of the cutting of the outlet as the ice was retreating, and that the water-level had actually been made to rise higher than its level when these deltas were made in the presence of the ice. If this explanation be correct, then at the south only, where the uplift of the outlet end of the basin could not maintain the water-level on the sides of the basin, would the range of the terraces be such as the cutting of the outlet alone would produce. Later, when the water-level began to fall throughout the basin, the ice had retired north of the Saranac River, and the range of terraces here seems to indicate that a differential northern uplift had begun.

Another interpretation.—The above has been written on the assumption that either the 580-foot Ausable, or the 640-foot Saranac gravel plateau, or both of them, are deltas made in the presence of the ice, and that the 500-foot Ausable and 520–540-foot Saranac deltas are the later product of erosion of the higher gravels. If it should be found that neither the 580-foot Ausable nor the 640-foot Saranac deposits are glacial deltas, but that the 500-foot Ausable and the 520–540-foot Saranac deltas are the highest, and if also some of the

more indistinct and uncertain terraces at Street Road and Crown Point be assumed not to be wave-wrought, then, because the wave-wrought terrace curve and the delta curve would be made to cross in the southern Champlain region, another succession of events must be assumed: After the ice had retired beyond the Saranac River, and after the 500-foot Ausable and the 520–540-foot Saranac deltas had been made in the Hudson-Champlain water body, the uplift at the south took place which inaugurated Higher Glacial Lake Champlain, and further uplift took place which tipped this water body into the northern end of the basin, causing it to rise to the level of the highest terrace in the upper series. The cutting of the outlet then permitted the upper series of terraces to be made.

On the whole it seems best to accept the reality of the upper terraces at Street Road and Crown Point, and to interpret these levels as in part Hudson-Champlain levels, and the lower part of this upper terrace series in the vicinity of Street Road and Crown Point and the entire upper series of terraces from the Bouquet River to north of the Saranac, as due to the waters of Higher Glacial Lake Champlain. While this may now seem to be the best interpretation, it certainly is not demonstrated.

ALTITUDE OF THE HUDSON WATER BODY.

If the Hudson water body was a lake, its height above sea-level is indicated by three things: (1) elevation of the southern barrier at that time; (2) height above sea-level of Lake Iroquois, which drained into this Hudson water body through the Rome outlet; (3) the amount of change in elevation of the barrier since it emerged from the Hudson water body, and produced Higher Glacial Lake Champlain.

Elevation above sea-level of the southern barrier.—If the submerged extra-morainic Hudson channel was used at this time, as a part of the outlet valley, and if the Narrows channel was cut entirely as an outlet channel, then the land must have been higher than now by 122 feet plus the amount of the slope of the channel to the sea. With the large volume of water flowing through this valley, it may have been cut to a very gentle gradient, and the elevation of the Hudson water body above the sea-level may not have been more than 35–50 feet. It may have been much more.

Evidence from the altitude of Lake Iroquois.—Since this lake drained into the Hudson water body, it follows that the Hudson water body was lower than Lake Iroquois. The level of the latter has been calculated at about 200 feet.[1] It follows then that the Hudson water body was less than 200 feet above sea-level, by the amount of fall of the outlet stream from Lake Iroquois to the Hudson water body. If the lower delta of the Mohawk described by Professor A. P. Brigham at Schenectady (340 feet A. T.) was deposited by the Mohawk and not by streams of ice-water from the ice-front,[2] it would require an average slope of this outlet stream of less than $2\frac{1}{2}$ feet per mile to permit the Hudson water body to be above sea-level.

Amount of uplift of barrier south of Fort Edward since inauguration of Higher Glacial Lake Champlain.—Since the barrier is now no more than 260 and no less than 220 feet A. T. it follows either that the Hudson water body was above sea-level when the barrier emerged from it, or, if it was at sea-level, there has been an uplift of 220–260 feet since the inauguration of Higher Glacial Lake Champlain. Since changes in the gradient of the outlet valley require an uplift of 60 feet or so, since the close of Higher Glacial Lake Champlain history,[3] it leaves an uplift of 160–200 feet to take place during the history of this lake. If there was this amount of uplift during this time, then the Hudson water body was at sea-level when the barrier which produced Higher Glacial Lake Champlain emerged from its waters.

ORIGIN OF HUDSON WATER BODY.

There are two hypotheses to explain this water body.

1. (*a*) The water body was a lake made by a barrier at the south. (*b*) There was a succession of lakes made by a succession of barriers, or by a migrating barrier.

2. The water body was an arm of the sea.

Aside from the deposits made in its waters there are four series

[1] *Monograph 41*, U. S. Geological Survey, p. 775.

[2] *Bulletin of the Geological Society of America*, Vol. IX (1898), p. 205.

[3] This is based on the assumption that the valley at Whitehall has not changed in level and was 120 feet above sea-level when Higher Glacial Lake Champlain fell 120 feet to "Marine" Champlain level, and on a reasonable assumption as to the slope of this outlet valley.

of phenomena that must be accounted for in any explanation of the Hudson water body. They are: (1) the rise in level of the deltas and gravel plateaus northward; (2) the submerged channels, both in the lower Hudson and in the upper Hudson as far north as Troy; (3) the gap in the moraine at the Brooklyn Narrows, and the gap in the moraine at Perth Amboy, occupied by Arthur Kill (see Fig. 8, p. 426); (4) the scarcity of wave-wrought features.

1. *The rise of the gravel plateaus northward.*—Under either of the above hypotheses the land was relatively lower at the north during the presence of the water body than it is now, and there has been subsequent greater northern uplift. This greater northern uplift is necessary to account for the disappearance of the Hudson water body, if it was a lake, because the depth of the floor below the delta levels exceeds the known amount of the cutting of the outlet.

If the Hudson water body was a lake, the amount of northern uplift necessary to produce the present altitude of the deltas is greater than the amount necessary if they were formed in the sea, for the following reason: As the ice was retreating, the outlet was being lowered, so that the more northerly deltas must have been made at successively lower levels, unless there was some action to maintain the water-level. If the amount of cutting of the outlet be distributed among the sixteen or more different stands of the ice south of Street Road, it would cause but a small amount of fall between the successive stands. Even if the effect of the accession of the waters from Lake Iroquois by way of the Rome outlet be taken into consideration, and reasonable allowance be made for the increase in rate of cutting after that, it makes the fall in water-level between successive positions of the ice a comparatively small amount, much less than could be read from the topographic maps. Inequality in level of deltas due to this cause is much less than that due to unequal building up at the successive positions of the ice. In the aggregate, however, the amount of fall of water-level is considerable. If the cutting of the outlet during the history of the Hudson water body was 122 feet, it requires that the last delta made in this water body undergo an uplift of 122 feet more than would be required if they were all built in the sea at one stand of the land.

2. *Origin of the submerged channels.*—Under the first hypothesis

(the lake hypothesis) the land was not only relatively lower at the north than now, but at the south, from the beginning of the ice-retreat or soon after, it was higher than now. Its final altitude, however, before the recent submergence may not have been its altitude when the ice began its retreat. If the land at the south had its full altitude when the retreat of the ice began, then depression only is necessary here since then. If the full altitude was attained only after the ice had retreated some distance, the movement at the south was first one of uplift and finally one of depression. During the higher altitude, the channels, which are now under the waters of the Hudson estuary, were eroded and subsequent depression of the land has submerged them. Under the estuary or salt-water hypothesis the land was lower than now both north and south, when the gravel plateaus and other standing-water features were produced, and was subsequently uplifted; erosion produced the channels, and subsequent depression submerged them. Under either hypothesis, then, the retreat of the ice was followed by a time of higher altitude of land than now, and was succeeded by one of depression. The chief difference in the hypotheses is in the original altitude of the land and the time of uplift. According to the salt-water or estuarine hypothesis, the time of uplift was on the inauguration of Higher Glacial Lake Champlain, although the uplift may have been in progress in the southern Hudson before the emergence of the barrier in the northern Hudson that produced Higher Glacial Lake Champlain. The amount of this uplift before the disappearance of the Hudson water body is limited, however, by the levels which would give the sea access to the northern Hudson, if the water body was an arm of the sea. According to the lake hypothesis, the land was higher than now when the ice began its retreat, or soon after, and had either attained its full height then or did so during the retreat of the ice. According to either hypothesis, the full altitude of the southern Hudson had been attained before the close of Higher Glacial Lake Champlain history, and probably southern depression had begun.

3. *The gaps in the moraine.*—There are two gaps in the moraine between Brooklyn and Perth Amboy, the Narrows gap and the Arthur Kill gap (p. 426). The gap occupied by Arthur Kill has slopes which indicate that it may have been cut down from an elevation of from 25

to 40 feet above tide. The Narrows gap has steep slopes, which indicate that it may have been cut down from an elevation of 60 feet above tide. These estimates are not so reliable as they would be if the gaps were cut in a plain, because the moraine surface rises and falls, and a depression at a lower level than that indicated by the top of the steep valley side may have existed where these gaps now are.[1] However, it does not affect the results greatly whether the height of the barriers was a few feet more or less than the above estimates, but it is a matter of considerable importance to know whether the sea had access to the Hudson without an altitude of the land lower than the present, as the ice was retreating from the Brooklyn-Perth Amboy moraine. While it cannot be said to be demonstrable, the weight of the evidence seems to indicate that it did not.

According to the hypothesis that the Hudson water body was an estuary, these gaps must have been first scoured out when the land was enough lower to permit the sea to enter and the tide to scour. This requires a depression somewhat less, possibly, than 60 feet for the Narrows gap and 25–40 feet for the Arthur Kill gap. According to this hypothesis, tidal scour must have lowered these gaps to such an amount that, on the subsequent uplift which permitted the submerged channels to be carved out, either there was free passage for the streams that flowed through them, or they were scoured to a level lower than that of any other part of the barrier, and thus took off the drainage which finished the work of cutting away the barrier.

According to the hypothesis that the Hudson water body was a lake, these gaps were made by the outflow of fresh waters and not by tidal scour. This does not refer to the gaps at their present level, which may in part be due to tidal scour since the recent depression, but to their depth before the recent depression. If these gaps were cut by outflow of fresh waters, their relations are such as to require first a cutting as outlets of independent lakes, and later, when the ice had retired far enough to permit these independent water bodies to

[1] Professor Salisbury has suggested that these steep slopes may be due to recent wave-action. If this be the correct explanation, it makes the amount of cutting of the gap through the moraine even less certain. If, however, the overwash plain fronting the moraine was once continuous across the Narrows, as seems likely, the altitude of its inner margin (20–40 feet A. T.) marks the level from which the gap has been cut here.

coalesce, either (1) they did coalesce or (2) the outlets had been cut enough to so lower the water-level of each that they remained independent. If the lakes coalesced, then either (*a*) one of the outlets had been cut lower than the other, and thus rapidly drew off the water below the level of the other, or (*b*) both persisted and were rivals in the task of draining the lake.

In order that the requirements of the situation be clearly understood reference must be made to the maps showing the gaps and their relations to the present channels (see Fig. 8, p. 427, and Fig. 7, p. 425). From these maps it is observed that the Arthur Kill gap opens southward from Newark Bay, and that the Narrows gap opens southward from New York Bay. Newark Bay and New York Bay are connected by Kill van Kull ten miles north of Arthur Kill gap. New York Bay is connected with Long Island Sound by East River. The east end of Long Island Sound opens to the sea by wide channels. The land on the sides of both Kill van Kull and East River seems to indicate that the channels which they occupy have not been cut from much above sea-level. It follows, therefore, that if Arthur Kill and the Narrows gap were cut at first as outlets of independent lakes at the ice-front, and later as rival outlets of a water body that covered Newark Bay and New York Bay, they must either have been cut below the level of the divide between Long Island Sound and New York Bay before the ice retreated beyond it, or the present gap at the east end of Long Island must have been closed by a higher altitude of the land. Otherwise the Narrows gap at least would have been abandoned for a lower channel into Long Island Sound. While it is not at all unlikely that the gap at the east end of Long Island was closed, it is not essential for our present purpose to assume this. The writer, however, believes that the hypothesis that the present gap at the eastern end of Long Island was closed at that time by a greater altitude of the land is as tenable an hypothesis as any to account for the water body in which accumulated the recent clays of the Connecticut Valley and other valleys opening into Long Island Sound. It is in harmony with the published facts in regard to the distribution of those clays.[1] However, this is aside from the point under discussion.

[1] See N. S. SHALER, J. B. WOODWORTH, AND C. F. MARBUT, "Glacial Brick Clays of Rhode Island and Southeastern Massachusetts," *Seventeenth Annual Report*, U. S. Geological Survey (1895–96), pp. 957–1004.

If the Narrows gap and Arthur Kill gap were started as outlets of independent lakes at the ice-front, then by the time the ice had retreated far enough to permit these water bodies to coalesce, either both had been cut below the divide now crossed by Kill van Kull, and had thus produced independent water bodies in Newark Bay and New York Bay, or they became rival outlets to a common water body. If they became rivals, then one of the following things happened: One of them drew off the water below the level of the other, or before either one was victorious both had succeeded in cutting below the level of the land along Kill van Kull, and thus produced independent water bodies (in Newark Bay and New York Bay). If one was victorious, the Narrows gap, since it finally became the deeper, presumably was the one. Under this interpretation the Newark Bay Lake became tributary to Hudson Lake. Arthur Kill may have remained, however, the channel of the Rahway-Woodbridge Creek system (see Fig. 8), and thus have been deepened more. In either event, the Newark Bay water body became independent and drained either through Arthur Kill or by way of Kill van Kull. The deposits in the lowlands west of the Palisade Ridge were made in this independent water body. If Arthur Kill remained the outlet, then the present Kill van Kull channel is due either to tidal scour or to the work of a tributary working back from the Hudson, or to both. If Arthur Kill was abandoned, and Kill van Kull was the outlet of this Newark Bay Lake, the present channel is due to cutting by the outflow of its waters and to subsequent tidal scour, and Arthur Kill gap is due partly to cutting as an outlet of a lake, and later to cutting by the Rahway-Woodbridge Creek, and no doubt also to some recent tidal scour.

If the present channels be accepted as inheritances from the past, and not due to tidal scour, or at least not enough to obscure their former relations, it would seem that the Hackensack-Passaic system, along with Elizabeth River, finally became tributary to the Hudson through Kill van Kull on the disappearance of Newark Bay Lake, and that the Rahway River with Woodbridge Creek formed a system flowing through the Arthur Kill gap. If the submerged channel outside the moraine near Princess Bay Light, likewise is an inheritance from the past and not due wholly to tidal scour, the Rahway-Woodbridge

system was tributary to the Raritan, which, presumably, was tributary to the Hudson. The connection of the submerged Raritan and extra-morainic Hudson channel, however, cannot now be traced.

4. *Scarcity of wave-wrought features in the Hudson Valley.*—The almost complete absence of wave-wrought terraces in the area of the Hudson water body south of Glens Falls is not what would be expected. Even faintly developed terraces have been observed at a few places only. This apparent lack of effective wave-action may be due to the following:

(1) In the presence of the ice-sheet the water body was frozen over for considerable periods of the year, and during the summer season the presence of floating ice would tend to reduce the effectiveness of the wind in producing waves. This explanation would apply on either hypothesis for the origin of the Hudson water body. It would be more applicable if the body was a lake, but would apply if the water body was the sea, and if much freshened as suggested below (p. 650), it would be nearly on a par with the action in a lake.

(2) After the ice-sheet had retired to the northern part of the area, these conditions would no longer exist or would be much weakened in their effect and wave-action would be expected. (*a*) It is to be noted here, however, that the southern part of the area is the narrow part where the wind would have comparatively little chance to produce effective waves, even under the most favorable conditions of temperature. The greater width of the water body in the northern part of the Hudson would seem to necessitate effective wave-action after the ice retired into the Lake Champlain region and the climate had become warmer, so that the surface was no longer frozen over for so large a part of the year. Too much emphasis, however, must not be placed on the warming up of the climate, for boreal willows in the Salmon River section indicate a climate considerably colder than the present in Marine Champlain time. (*b*) It is to be noted, also, that this wide northern part of the Hudson water body was divided into smaller portions by numerous islands and shoals (see Fig. 13, p. 437), and these would decrease the efficiency of the wind in producing waves. (*c*) If this water body disappeared shortly after the ice had reached the Champlain valley, the length of time for this effective wave-action was reduced, and the earlier the dis-

appearance the more applicable the explanation becomes. If the Hudson water body existed until the ice had retired to the Bouquet River, or beyond the Saranac, as is considered in the various hypotheses stated for the time of origin of the Higher Glacial Lake Champlain, then there was a long time for the production of shore terraces. The time necessary to make the secondary deltas noted on the Batten Kill and the Hudson River would seem to be ample for the development of distinct wave-wrought terraces, and it is in this part of the valley only that features have been observed that may be assigned to wave-action, but it is surprising that they are not better developed here. (*d*) There is evidence that the water-level was not constant. Possibly there were two things to make it inconstant: first, the cutting of the outlet, and, second, crustal movement. The first could be true, of course, only if the Hudson water body was a lake. The second could be true under either hypothesis for the origin of the water body, and, as mentioned above, is necessary for the disappearance of the water body under either hypothesis.

Altogether the slight development of wave-wrought features in the Hudson is unexpected, and the above explanations do not seem to be wholly satisfactory, especially when it is recalled that under apparently very similar conditions distinct wave-wrought features were made in the Champlain region. The writer is forced to believe that a more detailed examination of the Hudson region will bring to light more evidence of wave-action.

Features unexplained by the salt-water hypothesis.—Certain features are present which are in accord with the lake hypothesis, but not with the salt-water hypothesis. There are certain features not present which seem to be required by the latter hypothesis, but not by the former. If the Hudson water body was an arm of the sea, the presence of some of these features and the absence of others must be accounted for. These features are: (1) absence of distinct wave-wrought features at the outer edge of the Brooklyn-Perth Amboy moraine at the levels required by the hypothesis; (2) presence of the overwash plain on Staten Island and Long Island without distinct features to be ascribed to wave-action; (3) entire absence of life certainly marine in the deposits made in the Hudson water body; (4) apparent absence of tidal distribution of muds in the Hudson

water body; (5) evidence of the altitude above sea-level of the Hudson water body.

1. Absence of distinct wave-wrought features at the outer edge of Brooklyn-Perth Amboy moraine.—There is an absence of wave-wrought features of a decisive character outside of the moraine in a region where the materials are soft and easily washed and which must have been exposed to strong waves from the Atlantic. Although these materials are displayed with a topography which would not offer the best opportunity for effective wave-action, yet it seems incredible that the sea could have been present over the area outside of the moraine, at the levels demanded by the gaps in the moraine and for the time necessary for the tide to scour out these gaps to the required depth, without leaving a decisive record in the easily eroded drift. Three suggestions aiming at an explanation of this are as follows: (*a*) That these gaps were first made by the wearing of ice-waters before depression took place, and were subsequently deepened by tidal scour when the land had been depressed enough to admit the sea. If this be admitted, the same early conditions as those under the lake hypothesis are assumed, the main difference being in the time of depression and in the number of depressions. (*b*) That ice protected the shore from wave-action. This would seem plausible for the time when, and the places where, the ice was present, but is difficult of acceptance after the ice-edge had retreated. Shore-ice might, however, have remained for long periods of the year, after the ice-sheet had retreated. (*c*) The land rose rapidly after the original depression, thus preventing the making of a distinct record of wave-action. If this was so, equally rapid scouring of the channels must be postulated in order to acccount for the access of the sea to the Hudson Valley. It is doubtful if the rapid rise would be effective unless the movement was very rapid, and then the scouring would be handicapped.

2. Presence of the overwash plains at the ice-front.—The presence of the overwash plains at the ice-front on Long Island and Staten Island without distinct features to be ascribed to wave-action, or a form that the presence of the sea over them would lead one to expect, argues strongly for an altitude of land above sea-level when the overwash plain was building. If the submergence hypothesis is tenable, it would seem necessary, as above, to postulate an altitude of land at

least as high as the present when these overwash plains were made, and higher than that when the gaps in the moraine were being cut, with enough subsequent depression to give the sea access, thus forming the Hudson water body. Such a crustal movement is the opposite of what would be expected as the ice retreats.

3. Absence of life certainly marine.—The only fossils that have been found in deposits in the Hudson water body are: (1) sponge spicules, fresh-water diatoms,[1] and worm tracks at Croton; and (2) leaves of *Vaccinia oxycoccus* at Albany.[1] No marine fossils have been found, unless the sponge spicules are such, and their identification, it seems, is uncertain. The presence of fresh-water diatoms is not necessarily fatal to the hypothesis of a salt Hudson water body, for they may have been brought into the salt water by the streams and deposited with the sediments in the salt water. If the sponge spicules are those of salt-water sponges, and if they were found in clays which antedate the recent depression, they settle the question of the origin of the Hudson water body.[2] Although there is an entire absence of life certainly marine in the deposits of this time throughout the entire stretch of 240–265 and possibly more than 300 miles through which the Hudson-Champlain water body extended (see Fig. 22), in the northern portion of the same region there is abundant evidence at low levels of marine life, which came up the St. Lawrence after the Hudson-Champlain water body had disappeared. Unless there is a sufficient explanation, this must be admitted as a strong argument against the salt-water hypothesis. However, it must be admitted that there is likewise a paucity of any forms of life in the Pleistocene deposits of the Hudson Valley. In explanation of the absence of marine life in this hypothetical long arm of the sea three

[1] See footnotes 3 and 4, p. 454.

[2] These sponge spicules were reported from Croton by Mr. Heinrich Ries in 1895. Since the above was written and first placed in the hands of the printer, word has been received from Mr. Ries that the sponge spicules are those of species not confined to salt water. The exact locality at Croton from which the specimens came is also a matter of some uncertainty. That they came from 20 feet below sea-level and were found in solid lumps of clay is certain, however. Inasmuch as some of the clay used at Croton for brick-making has accumulated in the Hudson estuary since the recent depression, it is possible that the clay in which these specimens were found was deposited long after the disappearance of the Hudson water body, and that therefore the fossils mentioned have no bearing on the origin of the Hudson water body.

suggestions have been made: (1) The waters were cold while the ice was near. (2) The waters were muddy while the ice was near. (3) The waters were freshened because of the great territory—at one time the Great Lakes drainage basin—drained into this water body, and because of the shallow sill over which little salt water could pass.

(1) In regard to the first suggestion it may be said that the waters were cold, but they were decreasingly cold as the ice retreated 240–300 miles and more northward. In Greenland, at the present time, marine life is abundant in the waters close to the ice-edge,[1] so that even if the waters were cold it does not appear to be a sufficient reason for the absence of salt-water life. Further than this, marine life invaded the Champlain region soon after the ice had retreated across the St. Lawrence and permitted the sea to enter. The fact that it failed to do so during the much longer time it had to get into the Hudson from the south while the ice was retreating northward argues strongly against the salt-water hypothesis.

(2) The waters were muddy. This argument would hold good so long as the ice was near. When at a greater distance, the argument does not hold good, for it seems to be true that there was comparatively little deposition of muds at a distance from the ice. Were it not so, the kames and other ice-molded forms at low levels would have been buried. The presence of marine life in the clays on the coast of Maine, and also in somewhat younger clays in the Lake Champlain region, indicates that marine life could exist while the deposition of considerable fine sediment was taking place. The explanation of the absence of life because of the muddiness of the waters therefore does not carry conviction with it, especially since there was so much opportunity for the introduction of life after the ice had retreated a great distance and the waters had become clear.

(3) The water was kept fresh because of the shallow sills over which the salt water had little access. This is perhaps the best explanation offered.[2] It necessitates a higher altitude at the east end of Long Island Sound than the present; otherwise there would

[1] Verbal communication of Professor Chamberlin. See also R. D. SALISBURY, *Glacial Geology of New Jersey*, p. 513.

[2] See R. D. SALISBURY, *Glacial Geology of New Jersey*, Final Report of the State Geologist, Vol. V, pp. 511–13.

have been abundant opportunity for life to come into the Hudson over the low land between Long Island Sound and the Hudson, and the Connecticut Valley deposits, which appear to resemble those of the Hudson in many respects would be expected to show abundant marine life.

It may be said, however, that this argument of shallow water over the sills has its limitations. It has been shown that it is necessary to believe that the channels through the moraine were cut down a considerable amount before the Hudson water body disappeared. On the submergence hypothesis tidal scour must be relied on to do this cutting, and reduction of the amount of water to get in over the sills at high tide reduces the amount that could go out with the ebb, and thereby proportionally reduces the efficiency of scour; and if none comes in, the scouring is reduced to the action of the fresh water supplied by the streams. This limitation would be more severe in Newark Bay perhaps than in the Hudson, where the great amount of fresh water flowing from Lake Iroquois into the Hudson waters after the Rome outlet came into use would be available for scouring the channel. The argument would not apply so well, however, in explanation of the absence of marine life in the Connecticut Valley. The demands of later events require a scouring out of the Hudson channel at the narrows to a considerable depth—possibly as much as 122 feet—before the Hudson water body disappeared. It would seem that this amount of scour would admit plenty of salt water and marine life. It may be, however, that water in the scoured channel was kept shallow by uplift, and the supply of salt water was thereby limited. Altogether it would seem possible that the explanation offered might account for the absence of marine life in the Hudson, if the delicate adjustment required to keep the water shallow over the sills existed. It is not known, however, that the conditions postulated actually did exist. The explanation would not apply to the phenomena in Long Island Sound, and in the Connecticut Valley, if the altitude of the land was as low as at present. It is doubtful if it is adequate even for the Hudson Valley phenomena without a higher altitude of land at the east end of Long Island Sound. This higher altitude is a requirement of the same kind, and nearly as great, as for the lake hypothesis in both the Hudson and Connecticut Valleys, and

greater than required for the Hudson Lake alone, which could have existed without this eastern uplift.

4. A fourth argument against the salt-water body is the absence of tidal action indicated by the fact that fine sediments were apparently not carried to any great distance from the ice-front. This is shown by a failure to bury some of the kames and other ice-molded features at low levels adjacent to higher gravel, sand, and clay. It may be said that this apparent failure of the fine sediments to be carried out on older and lower deposits in some situations, especially in the southern Hudson, is so extraordinary as to tax even the lake hypothesis. In some places this may be explained, however, by the persistence of protective stagnant ice-masses. There may be a question whether stagnant ice-masses would endure long enough to be thus effective. If there was sufficient tidal scour to cut the gaps in the moraine the amount required by later events, it is a question if the ice-masses could have endured long enough to prevent the burying of the kames, etc., by the finer sediments carried by the tide.

5. A fifth point bearing on the hypothesis that the Hudson water body was an arm of the sea is the evidence presented by its altitude when Higher Glacial Lake Champlain was separated from it. The evidence goes to show that its altitude at this time was something less than 200 feet above tide. How much less is unknown. If the amount of uplift while Higher Glacial Lake Champlain was being drained could be determined, the altitude of the Hudson water body when the barrier south of Fort Edward appeared would follow. (See pp. 639, 640.)

WHAT EVIDENCE IS THERE THAT THE HUDSON WATER BODY WAS A LAKE?

If the existence of a body of standing water be admitted, all the arguments against the submergence or salt-water hypothesis throw the scales in favor of the lake hypothesis. The evidence in favor of the lake hypothesis is as follows: (1) the existence of a barrier; (2) the evidence of deep channels cut through that barrier and submerged channels of drainage both inside and outside the barrier; (3, 4, 5, 6, 7) the five points mentioned above, as opposed to the salt-water hypothesis.

1. *The existence of a barrier makes the lake possible.*—Under the

sea hypothesis it also makes it necessary to explain the gaps in the barrier as, in part at least, due to tidal scour—an action which may have been limited (see the explanation for the absence of marine fossils as due to the shallowness of the water over the sills giving access to the salt water, p. 651). A barrier at the east end of Long Island Sound is not necessary for the existence of Lake Hudson, but an altitude of the land higher than now in that region is required by the supplementary explanation attached in this article to the salt-water hypothesis, and an altitude but little greater would produce a lake, and thus bring the Connecticut Valley phenomena and Hudson Valley phenomena under one explanation. It is not meant to imply here, however, that the Hudson and Connecticut water bodies were one water body. It seems certain that, if they were at an early date, they became independent later.

2. *The channels through the barrier and the submerged channels inside and outside the barrier.*—Under the lake hypothesis the outlet valley was a necessary feature, and the submerged channels are the natural consequences of the drainage of the lake, subsequent erosion by the Hudson, and later depression. Under the salt-water hypothesis the gaps must be explained as due to tidal scour which extended to a depth great enough to let the streams flow through them when elevation had taken place, but the completion of the channels was by the erosion of the Hudson at the subsequent higher stand of the land and perhaps by recent tidal scour. The lake hypothesis makes the gaps and extra-morainic channels now submerged, contemporaneous, in part at least, with the existence of the lake. The salt-water hypothesis makes them due in part to tidal scour, and in part to erosion following the uplift of the land and the consequent recession of the sea.

The channels inside the moraine in Newark Bay may be contemporaneous with the later history of the Hudson Lake. Under the salt-water hypothesis they follow uplift, but may be contemporaneous with deltas in the upper Hudson. The fact that the disappearance of the Newark Bay water body followed an uplift of the land of just about the amount necessary to cause this water body to disappear favors the submergence hypothesis (see p. 657).

ARGUMENTS OPPOSED TO THE HUDSON LAKE HYPOTHESIS.

There are two possible arguments against the lake hypothesis. One of them is based on the altitude of land farther south in New Jersey. Certain terraces on the south shore of Raritan Bay and south form in part the basis for belief in the lower altitude of land in that part of New Jersey, but such terraces are not found on the drift-covered north side of Raritan Bay.[1] This would indicate that the submergence which produced the terraces on the south side of Raritan Bay came earlier, and that, if it extended to the north side, emergence had taken place before the ice retired. Professor Salisbury assigns the date of the submergence which produced these terraces either to late glacial or post-glacial time,[2] but he considers the question of submergence in the vicinity of New York as still an open one.[3] The absence of distinct wave-wrought features on the Brooklyn-Perth Amboy moraine and on the overwash plain between Brooklyn and Perth Amboy does not favor the hypothesis of submergence there, and it is difficult to reconcile the absence of these features with the hypothesis of a lower altitude of land.

There is another objection to the lake hypothesis which, if it were valid, would argue for the salt-water hypothesis. It is that the southern barrier could not have lasted during the great time it took to make the clays in the region north of the moraine. As will be seen from the discussion of the origin of the gaps in the moraine, if the barrier consisted of the moraine only, and was limited to that part of the moraine above present sea-level, it must be admitted at once. It must be remembered, however, that at the time of maximum southern elevation the outlet stream was cutting through a wide stretch of land outside the moraine. As mentioned before, the shore line of this time may have been 95–100 miles farther south. It is very likely, also, that the outlet was never very high above sea-level, but that the uplift was taking place while the ice was retreating, so that the rate of cutting of the barrier would be kept close to a minimum. It must be remembered also that the character of the lower portions of the channels through the moraine is unknown. It may well be

[1] G. N. Knapp, verbal communication.

[2] *Glacial Geology of New Jersey*, p. 204.

[3] See *New York City Folio*, U. S. Geological Survey, p. 16.

that it is of such a nature as to resist erosion. It would be expected, indeed, that after a certain amount of erosion of the moraine the concentration of the larger bowlders which are common in moraines would form a pavement in the bottom of the channel and would check the down-cutting.

FIG. 27.—New York and vicinity as it would appear if depressed enough to permit the entrance of the sea over the probable original height of the barrier at the Narrows and at Perth Amboy, and if the depression south of the Raritan River were forty to fifty feet.

Black color indicates land not covered by waters during the hypothetical depression. The outline represents the present coast.

In conclusion, it may be stated that, while no single argument seems to be fatal to the salt-water hypothesis accounting for the

Hudson water body, unless those drawn from the phenomena on the outside of the moraine be such, it is likewise true that the facts are not fatal to the lake hypothesis, unless the sponge spicules reported from Croton represent salt-water species.[1] Aside from these sponge spicules, the weight of the evidence seems to be in favor of the lake hypothesis.

RELATION OF HUDSON WATER BODY TO THE CONNECTICUT VALLEY WATER BODY.

If the Hudson water body was an arm of the sea, there is no need of discussing the relation between the Connecticut Valley deposits and those of the Hudson more fully than they have already been discussed. It is enough to repeat here, what has been said before (p. 651), that in order to account for the absence of life certainly marine in the Hudson, on the hypothesis stated above (p. 650), it seems necessary to postulate a higher altitude of the land at that time at the east end of Long Island Sound, so as to shut out free access of salt water to both the Connecticut Valley and the Hudson Valley.

If the Hudson water body was a lake, it does not necessarily follow, of course, that the Connecticut Valley deposits accumulated in a lake. This explanation is given for these deposits in Massachusetts.[2] It is true nevertheless that a southern uplift somewhat more than that necessary to make Hudson Lake would equally well account for the phenomena of the Connecticut Valley. So far as published accounts indicate, there is little, if any, clay of late glacial age, outside of the area north of Long Island Sound, which could not be explained as having accumulated either in local lake basins, or in the sea when the land at the north was depressed enough to submerge the clay areas along the eastern New England coast. This northern depression is not incompatible with the southern uplift which would produce a lake in Long Island Sound and in the valleys and lowlands north of it. If Long Island and the land to the east were high enough to make a lake north of it, either from the start or later on, this water body was divided into several parts.

[1] See footnote, p. 649.

[2] See Emerson, *Monograph XXIX*, U. S. Geological Survey, Chap. 19.

RELATION OF HUDSON WATER BODY TO WATER BODY WEST OF PALISADE RIDGE.

As already indicated, if the Hudson water body was an arm of the sea, so also were the waters in the lowland west of the Palisade Ridge by the time the ice had retired beyond the Sparkill Valley or earlier. If the Hudson water body was a lake, the waters west of the Palisade Ridge,[1] which may be called Newark Bay Lake, were probably independent while the ice was present and either drained through Arthur Kill, or first through that outlet and later into the Hudson by Kill van Kull. This Newark Bay Lake, no doubt, disappeared long before the Hudson Lake. It is interesting to note that when the ice had retreated beyond the Sparkill Valley, which crosses the Palisade Ridge just north of the New Jersey boundary (Fig. 9, No. 14, p. 429), the waters of this Newark Bay water body coalesced with those of the Hudson water body through this narrow valley, the bottom of which is now 20–30 feet above tide at the west side of the Palisade Ridge. Since the land was at this time down at the north by 75–90 feet more than at the south, it follows that this Sparkill Valley was the lower outlet, and that when the Hudson water body had been lowered to the level of this valley, the Newark Bay water body disappeared. Whatever cutting, therefore, was done at a southern outlet was accomplished before the ice had retired beyond this valley. It is likewise interesting to note that with this amount of northern depression the slope of the Hackensack Valley floor, for instance, would have been just the reverse of the present. If, when the water body disappeared this was true, the lower Hackensack, for instance, and other streams would have flowed in the reverse of their present direction and joined the Hudson water body through the Sparkill Valley. Since there is no evidence, so far as the writer is aware, that such a reversal has taken place, it would follow that by the time the Hudson water body disappeared there had been an uplift sufficient to produce a slope southward. That uplift must have been as much as 45–60 feet, and may have been more. Since the water-level must have been lowered this same amount in order to disclose the floor, it would seem that the disappearance of the water in this area was due to uplift. This

[1] For discussion of hypotheses to account for this water body see R. D. SALISBURY, *Glacial Geology of New Jersey*, pp. 195–200.

may have been true under either origin of the water body, and must have been true under the estuarine hypothesis. The early history of this water body was in part contemporaneous with that of Lake Passaic,[1] but the latter lake had disappeared before the Newark Bay water body had attained its greatest dimensions. When the Newark Bay water body disappeared, the floor was exposed as a broad stretch of plain partly covered with sand, through which the Passaic-Hackensack River took its course and was joined east of Shooter's Island by the extended course of Elizabeth River. From the sands of this Newark Bay lake-floor the dunes which occur on the west side of Newark Bay at various places were made.[2] If the peat under this sand is a salt marsh accumulation, as Professor George H. Cook thought, the interpretation must be altered accordingly.

RELATION OF HUDSON WATER BODY TO LAKE IROQUOIS.

The delta of the Mohawk River in the Hudson water body is reported at 340 feet above tide.[3] If this was made at a time when Lake Iroquois was draining out through the Rome outlet, it shows that the Hudson water body had a level lower than Lake Iroquois, by an amount, however, not necessarily the same as the present difference between the Lake Iroquois level and the delta level.

If Higher Glacial Lake Champlain was inaugurated before the ice retired beyond the Adirondacks, then here is the only opportunity to determine the relation between the levels of Lake Iroquois and the Hudson or Hudson-Champlain water body. If Higher Glacial Lake Champlain was not inaugurated until after the ice retired beyond the Adirondacks, then the waters of Lake Iroquois must have fallen to the level of Hudson-Champlain, and subsequently had the same level as that of Higher Glacial Lake Champlain on the uplift of the barrier south of Fort Edward. The weight of the evidence, however, is against this succession of events.

1 See Rollin D. Salisbury and Henry B. Kummel, "Lake Passaic: An Extinct Glacial Lake," *Annual Report of the State Geologist of New Jersey* for 1893, pp. 225–328.

2 See *Geology of New Jersey*, 1868, p. 228, and *Annual Report of New Jersey State Geologist*, 1893, p. 205.

3 A. P. Brigham.

RELATION OF HIGHER GLACIAL LAKE CHAMPLAIN TO IROQUOIS.

Lake Iroquois was made by the ice blocking the St. Lawrence and causing the waters in the Ontario basin to overflow at the lowest point of the basin which was then near Rome, N. Y. During the retreat of the ice a differential uplift was in progress greater at the north. G. K. Gilbert says that when the Rome outlet (present level, 440 feet above tide) was abandoned at the close of the Iroquois epoch, "the water of the Ontario basin descended for a time along a course beginning near Covey Hill, and ending near West Chazy, N. Y."[1] Whether these levels are marked by shore terraces is not stated. If they are, it would seem that when the ice retired far enough north in the Champlain Valley, the waters of the Ontario and Champlain basins coalesced. This water body might properly be called Lake St. Lawrence—a name suggested by Upham in 1895.[2] If these levels are not marked by shore terraces, but simply by a series of outlet levels,[3] then it would seem that the waters of Higher Glacial Lake Champlain and the successor to Lake Iroquois did not coalesce, at any rate not until the close of Higher Glacial Lake Champlain time, when both fell to the levels which have been called "Marine" Champlain levels although the highest of these levels do not seem to contain marine fossils (see p. 626).

During "Marine" Champlain time these waters not only occupied the Champlain Valley, but extended into the Ontario basin, as is shown by the fact that the "marine" shores of the Champlain Valley extend westward through northern New York to the Ontario basin, being continuous with the so-called Oswego shore line.[4] In the Ontario basin as in the Champlain basin there is evidence of differential uplift greater at the north, in the late stages of the ice-retreat.

DURATION OF HUDSON WATER BODY.

If the Brooklyn-Perth Amboy moraine be correlated with the earliest Late Wisconsin terminal moraine, the history of the Hudson

[1] *Eighteenth Annual Report*, U. S. Geological Survey, Vol. I, p. 59.

[2] See *American Journal of Science*, Vol. CXLIX (1895), pp. 1–18; *Monograph XXV*, U. S. Geological Survey, p. 264. See also this article, p. 626.

[3] Since this was written and placed in the hands of the printer the writer has learned from conversation with Mr. Gilbert that this is the fact.

[4] G. K. Gilbert, *loc. cit.*

water body spans, or more than spans, the history of the entire system of moraines of that time represented in Ohio, Indiana, and Illinois. In terms of the history of the succession of the Great Lakes, it spans or more than spans, the history of Lakes Maumee, Whittlesey, Warren, Dana, and part of Iroquois,[1] and possibly all of the latter, according to the interpretation of the time of inauguration of Higher Glacial Lake Champlain. In terms of the history of Lake Chicago, it began earlier, and whether it ended earlier or later depends on the time the northern outlet of Lake Chicago was opened up by the retreat of the ice.

TIME DIVISIONS.

If the beginning of the retreat of the ice from the Brooklyn-Perth Amboy moraine be counted as Champlain time, then the time since the moraine was made may be divided as follows:

1. Hudson-Champlain.
2. Higher Glacial Lake Champlain.
3. "Marine" Champlain.
4. Present Lake Champlain.

Possibly the upper part of the levels marked "Marine" Champlain may represent another lake named by Upham Lake St. Lawrence, and thus make another division.

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[1] For an account of the history and relations of these lakes see Leverett, *Monograph* 41, U. S. Geological Survey, pp. 710-75.

REVIEWS

The Economic Resources of the Northern Black Hills. By J. D. IRVING. With Contributions by S. F. EMMONS and T. A. JAGGAR, JR. (Professional Paper No. 26, U. S. Geological Survey, 1904.) Pp. 222. 20 plates, 16 figures.

THIS report treats of the general geology and the economic or mining geology of an area of about six hundred square miles on the northeast flank of the great central dome of the Black Hills.

The essential structural features are: (1) the great central dome, now very greatly reduced and dissected by erosion, of laccolithic granite; (2) a border of greatly metamorphosed Algonkian sediments, which have been compressed into isoclinal folds, and whose strike is, in this district, northwesterly; (3) a great series of Paleozoic, Mesozoic, and Cenozoic sediments which dip away to the northward from the central igneous core. The central granite mass gave off great intrusive tongues which cut the Algonkian schists in all directions. Numerous later intrusions of porphyry are found in nearly all the formations from Algonkian to Benton.

On pp. 20 and 21 is to be found an excellent feature of this paper, namely, a summary, in tabulated form, of the essential points of interest in connection with each formation. Besides giving the usual facts needed for correlation, there is an additional column which is devoted to the essential topographic characteristics of each formation. From an examination of this, one can readily grasp how important a means in correlation the topographical element may become.

The chief interest in this region lies, of course, in the mineral wealth, and it is this phase of the subject to which the major part of the report is devoted. The main productive mining district is included in an area of about one hundred square miles, extending from the town of Perry, on Elk Creek, northwestward to the town of Carbonate, on the east bank of Spearfish Canyon, with its widest and most productive portion between Terry Peak on the southwest, and Gorden on the northeast. In the neighborhood of Terry Peak there has been the greatest igneous activity and also the greatest ore deposition.

The ore deposits are classified as follows: (*a*) those in the Algonkian;

(*b*) those in the Cambrian; (*c*) those in the Carboniferous; (*d*) those in eruptive rocks; and (*e*) those in rocks of recent formation.

The ore deposits in the Algonkian rocks include gold ores, copper ores, and tin ores. Of these the gold ores are the most important. The gold ores are also the chief ores in the region as a whole. The celebrated Homestake mines are working these ores.

However frequent the eruptive dikes and sills in the various formations, it cannot be said that the origin of the ores is due directly to the presence of igneous rocks, though they may be the ultimate source of the mineralizing solutions which made the deposits.

The ores in the Algonkian rocks occupy fractures and crushed portions in the schists, and are generally found to be richest beneath the overlying impervious shales of the Cambrian system. There seem to have been two principal periods of mineralization, one previous to the rhyolitic intrusions, and the other later.

The copper ores occur in small patches in the schists, and, so far as known, associated with graphitic schists, the graphite being supposed to have reduced the copper from the copper solutions.

The tin, in the form of cassiterite, occurs in two forms: (1) in pegmatitic granite, and (2) in placers. These deposits were never very extensively worked, and have been almost entirely given up since the collapse of the tin enterprise in the southern part of the hills. The tin is too much scattered thoughout the rocks ever to make it worth while to carry on extensive mining.

The ores in the Cambrian rocks are the ores of gold and silver in three forms, of which the second is the most important. These are: (1) gold-bearing conglomerates (fossil placers); (2) the refractory silicious ores; and (3) pyritous ores. Besides the gold and silver ores there are ores of tungsten, and lead and silver. The second group of gold and silver ores are called refractory because amalgamation has so far failed in their treatment, there being a great deal of secondary silica, pyrite, and fluorite in their constitution. They occur in channel-like bodies usually along the bedding planes of the dolomite, sometimes just beneath an impervious shale, and sometimes just below sills of igneous rock.

The ores in the Carboniferous limestone consist of two classes, neither of which is very important. They are likewise refractory, silicious ores of gold and silver, and ores of lead and silver. They were deposited, it is presumed, by ascending waters in fractures in the massive limestone, but without any particular concentration due to impervious beds, as in the earlier formations.

The ore deposits of later age are placer deposits along the numerous streams that head back in the central and older rocks of the region. Of all these the Deadwood placer is the richest.

The great number of admirable diagrams illustrating structure, and also the many excellent photomicrographs of the ores, are among the most valuable features of the report. The petrographic study of ore deposits is rightfully coming to command greater and greater attention from mining men as well as from scientists.

W. D. S.

Zinc and Lead Deposits of Northern Arkansas. (Professional Paper No. 24, U. S. Geological Survey, 1904.) By GEORGE I. ADAMS, assisted by A. H. PURDUE and E. F. BURCHARD. With a section on "The Determination and Correlation of the Formations" by E. O. ULRICH. Pp. 113, and 27 plates and maps.

THIS paper is a preliminary report rather than a final treatise on the district with which it deals. It represents a further prosecution of the study of the whole Ozark region wherein the same general principles of ore deposition will, doubtless, be found to prevail. It is very timely, as the scientific exploitation of the area cannot be said to have more than begun. The prospect holes greatly outnumber the productive workings, and the mines that are in operation lead a rather spasmodic existence.

The report deals with an area, comprising Marion county, the northern part of Searcy, the eastern border of Boone, and the northeastern part of Newton county, coming within the Yellville quadrangle, which lies in the much dissected plateau portion of the Ozark region, and is underlain by comparatively undisturbed sedimentaries that dip slightly southward toward the Boston Mountains.

These sedimentaries comprise Ordovician, Silurian, Devonian, and Carboniferous strata which have been moderately folded, fractured, and brecciated.

Ore was reported as occurring in this district by Schoolcraft as early as 1818. There are two ore horizons, the Yellville dolomite, Ordovician, the oldest formation exposed in the area, and the Boone chert of the Mississippian series. The ores are chiefly zinc blende and galena, but there is also a minor quantity of oxidized ore mined from the upper workings, and some zinc silicate, calamine.

The general movement of underground water, which was the medium by which the ores were concentrated, was essentially the same as that

which obtained in the Wisconsin and Missouri lead and zinc districts. In the opinion of the authors, however, there are some differences as compared with those regions. They believe that the metals were formerly disseminated chiefly in the Mississippian limestones, and that they were quite largely leached out of these and carried downward and deposited by downward circulation. The ores in the Boone chert formation are now found principally along fissures, while in the Yellville dolomite they are richest in the brecciated portions of the rock. Synclinal areas, on the whole, appear to be the most productive.

Secondary concentration by descending waters has certainly taken place; whether concentration by ascending waters has also taken place is not so clear. Messrs. Van Hise and Bain argue for an upward movement as the chief factor in the deposition of these ores.

Following the strictly geological part of the report is a more or less detailed description of the mines and prospects in the area, with excellent photographs and some valuable hints for the further exploration of the country.

The closing part of the paper is a rather general statement concerning the correlation of the formations of the region. As a number of fossil species, new to science, and many others not known outside of Arkansas, were found, a more detailed treatment of the faunas of this region will doubtless be forthcoming when Messrs. Ulrich and Girty shall have completed their studies of the material collected. The accompanying correlation table is a very helpful feature of the report.

It is to be hoped that the further opening up of the area will so facilitate the work of geologists that more details concerning the actual occurrences of ore and concerning structural relations will become known.

W. D. S.

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THE RELATIONS OF THE EARTH SCIENCES IN VIEW OF THEIR PROGRESS IN THE NINETEENTH CENTURY.[1]

FACTS of earth science have now been so abundantly acquired and so thoroughly systematized that there is some danger of our substituting the schemes in which earth-knowledge has been summarized for first-hand knowledge of the earth itself.

For a fundamental matter like the globular form of the earth we resort to a hand globe, so admirable in its imitation of nature that we must beware lest the little globe rather than the earth in its true dimensions satisfies our imagination. We have so conveniently divided the geological record of the earth's history into ages and periods that their easily repeated names are apt to replace the laborious conception of long divisions of time.

Our escape from the danger of taking scheme for fact has lain in the resort to individual observation, and the past century must long be famous for the extent to which advantage has been taken of the opportunity for outdoor study.

The earth has been explored and measured as never before. The lands have been mapped, the oceans have been charted by original observers. The air has been followed in its circuits, great and small. The structure of the earth's crust has been patiently traced out. Thus "Go and see" came to be our watchwords one hundred years ago. As long as we, like Antæus of old, can return to the earth for new stores of the strength that we find in facts, we need not fear being strangled by any voluminous Hercules of theory.

[1] An address delivered before the Department of Earth Sciences in the World's Congress of Science and Arts at St. Louis, September 20, 1904.

It is the active appeal to observation that has checked the freedom of speculation which our brilliant predecessors enjoyed in an earlier century, when their fanciful schemes were little restrained by the barriers of fact that have since then been built up on every side. Indeed, schemes came to be for a time so much in disrepute that some investigators wished to suppress theorizing altogether, as was seen in the effort to supplant the name "geology" by "geognosy." I rejoice that the effort did not succeed; for if earth science were really limited to facts of direct observation, it would be at best a dreary subject.

How uninspiring would be such a knowledge of tides as could be gained only by actual observation along the seashore! A collection of such records would be an orphanage, where the foundlings would doubtless be well cared for and thoroughly drilled in their little duties, and yet left without the inspiriting, enlarging influence of parental care that they find on adoption into the family of earth, moon, and sun.

Whatever the danger of schemes and theories, they give the best of life to our bodies of facts, and our science cannot survive without them. Indeed, we have come to know that the danger of systems and theories lies, not in their dependence on the imagination, but in the possibility of their careless growth and of their premature adoption, and even more in the acceptance of a personal responsibility for their maintenance, instead of leaving that responsibility to external evidence.

If there is any subject in which the aid of schemes and theories based on observations has been absolutely necessary for progress, it is earth science, where so many of the essential facts are invisible. It cannot be too carefully borne in mind that observation and theory are alike in their objects, however different they may be in their methods. Both seek to discover the facts of their science. One deals with facts that are visible to the outer eye; the other, with facts that cannot be seen, either because they are too small or too large for outer vision, or because they are hidden within the earth or in past time, or because they are impalpable abstractions or relations. In both, fancy is sometimes taken for fact, more often so perhaps in theorizing than in observing; but we must not for that reason give

up either means of investigation. We have learned that both observing and theorizing must be carefully conducted; and we have therefore replaced the earlier watchwords, "Go and see," with the later ones, "See and think." We may still give praise to those who apply themselves chiefly to gaining first-hand knowledge of observable facts, but we have learned to give greater praise to those who, on a good foundation of visible facts, employ a well-trained constructive imagination in building ingenious and successful theories which shall bring to sight the invisible facts. We have been longest familiar with the need of theory in those branches of our subject which have, by reason of association with mathematical problems, traditionally employed deductive methods in their discussion, as in earth-measurement; we are least familiar with it in those branches that have until lately followed for the most part inductive or even only empirical methods, as has so generally been the case with geography.

For example, in the study of the tides, already referred to, how unanimous we are as to the inadequacy of inductive methods; how universally we accept the marvelous theoretical scheme of interaction between planet and satellite, deduced from tidal theory; how we admire its extension to the supposed relation of the inferior planets to the sun! But in general geography, how little attention has been given to the deductive and systematic consideration of its many problems; how many geographers still look rather askance at those of their number who propose to treat geographical problems through theory as well as through observation! It seems to me clear that, while the earlier progress of geography was very largely inductive, the later progress has been largely determined by a free acceptance of deductive as well as of inductive methods, and that geography as well as geology is today profiting greatly from the use of our faculty of insight as well as of outsight.

The objections that are not infrequently urged against the employment of indirect, inferential, as well as of direct, observational, methods in certain branches of our science come from two sides. On one side is a misapprehension as to the nature of our tasks, a belief that our work may really be largely inductive, that observation alone will suffice, if patiently continued, to discover all pertinent facts. This is a serious mistake; there is everywhere more unseen than seen.

On the other side is the fear that theories may become our masters, and that we may appeal to them as infallible, and thus set ourselves up as authorities. This is a most natural induction from the history of our earlier progress, for we have repeatedly seen the sincere young investigator grow into the impatient old autocrat; it is a bit of human nature that we share with the rest of the world; it is analogous to the change of meaning in the word "tyrant," from a mere king to an arbitrary despot. But there is another verbal analogy in the change of the word "skeptic" from inquirer to doubter, and it is this analogy that we are now following. We have learned to doubt because we know we may be deceived; we mistrust careless eyes as well as careless thoughts, and insist that careful scrutiny be given to the work of both; we reduce the dangers of theorizing just as we reduce the errors of observing, not by avoiding that indispensable means of investigation, but by practicing it carefully, until we become experts in thinking as well as in seeing; and all this constitutes an important element in our recent progress.

In spite of what has already been gained by good theorizing, few realize how largely earth science, apparently a matter of observation, is really built up of inferences that go far beyond mere inductions. Many of the inferences have gained a certification so good and so familiar that in respect to verity they take rank with seen things, and we are apt to forget their origin. The successive deposition of bedded rocks, the organic origin of fossils, the original horizontality and continuity of folded and eroded strata—these inferences are today accepted as if they had never been doubted; but they all were once doubted, and they had to make their way against opposition. Whatever order of certainty they have now acquired, they are not facts of observation, but facts of inference; and, like the great body of earth science, these now well-accepted facts of past time have not been determined by direct seeing, but by inference on the basis of seeing. We may therefore justly claim great progress for earth science, not only in the extent and accuracy of our observations, but also in the extent and accuracy of our inferences. While there is yet need of more conscious recognition and more thorough training, especially in the deductive processes by which many problems may be solved, we may still say that among the most significant steps we

have taken in the past century are those by which the necessity and the value of theorizing have gained frank acceptance among investigators, and by which many of the results of theorizing have gained an order of verity that compares well with that of facts of mere observation.

An illustration of this phase of our progress is to be found in two definitions, each of which has a certain currency. By some writers, geology is defined as the study of the earth's crust, thus emphasizing the observational side of the subject; by others, geology is defined as the study of the earth's history, thus giving fuller recognition to the growth of inference upon observation. The second definition does not lessen the essential importance of observation as the foundation of knowledge, but it accords a proper value to inferences, and in this way is characteristic of what seems to me sound scientific progress. The earth's crust contains the incomplete, partly concealed, partly undecipherable records on which we are to construct the science of geology; just as human monuments and writings are the records on which we are to construct human history; but in neither case are the records and the history identical, for the history in both cases includes a great body of inferences as well as of more directly recorded or observed facts.

The wholesome appeal to observation in the search for visible facts has loosened the control of supposed authority and has given us much of the freedom necessary for progress; but the assistance of the trained imagination in the search for invisible facts has in a far greater degree corrected the assumptions of an earlier stage of inquiry; it has even revised the dicta of philosophy and remodeled the dogmas of religion.

The inferential element of our progress has worked most beneficently. It is largely through our inferences that we have come to recognize the interdependence of the different parts of earth science. The climatologist may remain as provincial as he wishes; or he may enter through the gateway of present conditions the vast domain of past time, and on the way make friends with all the world; for he will then join hands with the petrographer, who has evidence of ancient desert conditions in the form of the grains in certain sandstones; and with the paleontologist, who infers the existence of ancient ocean

currents from the drift of graptolite stems; and with the glaciologist, who is asking the astronomer and the physicist whether one or the other of them can best account for the Pleistocene ice-sheets.

Not only do the different parts of earth science thus connect with one another, but, as the last illustration showed, they interlace most interestingly with the branches of other sciences in the forest of knowledge. The systematist would, indeed, be at a loss to classify our work, if in classification he thought to keep it apart from other kinds of work. Better let it grow up naturally with interlacing tree-tops and crowded underbrush, each tree showing its individualized effort in the universal competition, than seek to trim it into an orchard of separate trees. The departments and sections into which we are divided in this congress do not represent objectively disconnected groups and units of knowledge, but associated parts in contiguous growths of acquisition; we must not hesitate to go out of conventional bounds and to trespass, as it is called, on other departments, when it is to our advantage. Others are surely free to do the same by us. When we employ methods called mathematical and physical in our study of the winds, the profit is not only found in direct results, but also in the use of deduction and experimentation, so familiar in mathematics and physics, and so much less practiced, yet so much needed in all parts of earth science; in return we supply data for the study of the phenomena of gases on the largest terrestrial scale.

We must be chemists, geometricians, and physicists in studying the minerals of the earth's crust; and in return we supply to the chemist a great variety of natural compounds, and to the physicist the material basis for a remarkable variety of optical phenomena. We must indeed marvel at the skill displayed by minerals—which invade, colonize, migrate, and settle again in the dark inner world—in handling external rays of light, and we may wonder if they have not had some preliminary practice on radiations of a kind that physicists have yet to describe. Admirable also are the crystalline forms that give realization to the early inventions of geometers, much in the way that planets and comets give us in their orbits great natural examples of the conic sections, familiar for centuries as mathematical abstractions.

But it is particularly with biology in all its branches that we have

learned to borrow and lend. The evolution of the earth and the evolution of organic forms are doctrines that have reinforced each other; the full meaning of both is gained only when one is seen to furnish the inorganic environment, and the other to exemplify the organic response. Without question, the interaction here discovered in the working of two great processes is the most notable discovery of the past century, not the less glorious because we share it with other sciences. For if they have to do with the players, we have to do with the scenery and the properties for the all-world stage, where the success of the players has been conditioned by our setting since the play began. In the universal habit of respiration as a means of gaining the energy by which all plants and animals do their life-work, we see a successful response to the presence of free oxygen, mixed in the air or dissolved in the waters, and hence we infer that free oxygen has been present in atmosphere and oceans, at least as long as life has existed on the earth. In the development of stem and root, of dorsal and ventral parts, we perceive the everlasting persistence of gravity; to fail in the recognition of this elementary example of interaction between life and environment would be on a par with neglect of the earth's rotation because the evidence of it is found in the commonplace consequences of sunrise and sunset.

The races of mankind, so inappropriately treated as a chapter of physical geography in many of our text-books, but really the prime factor of political geography, are obviously determined by the larger features of the lands; just as the development of the higher organic forms has been determined not on the monotonous ocean floors but on the lands, where variety has really been the very spice of life.

If we turn to history—not simply to the politics of the past, but to the real history of human thought and action—the progress of our own science furnishes innumerable examples of response to environing opportunity: how natural that the later geological series should have been first deciphered in England, where it is so well displayed; that the study of earthquakes and the invention of seismographs thrive in Italy and Japan; and that geomorphy advanced rapidly in our arid West through the study of the nude, just as sculpture flourished in Greece.

It is but the commonplace of economics to show the large depend-

ence of modern civilization on the occurrence of mineral deposits. Like the quiescent crystalline forces in the rounded quartz grains of ancient sandstones, still capable of determining the settlement of new molecules around the old ones, the marvelous stores of dormant energy and strength in beds of coal and iron ore have long bided their time. After ages of neglect, they have become the centers of great populations; and now that our princes of industry have through countless difficulties touched and awakened them to life, we find a new meaning in the old fairy story of the Sleeping Beauty.

Even those broader considerations that we meet in philosophy and religion have developed new phases as the schemes of earlier times have been modified in view of the geological record: the place of work in the world, not a curse, but a duty; the date of the golden age, not behind us, but ahead; the view of death, not a punishment, but a natural element in the progress of life; even the conception of immortality has come to be—with some—directed less to speculations about a continued life elsewhere than to the study of the continuity of life here.

Religious ideas themselves—at least when we examine them objectively in the beliefs of others than our own people—are seen as if in a mirror held to nature; and the very gods of the lower religions are but reflections of the powers of earth.

It is only when we consider these broad phases of earth science that we gain our share of profit from the revolution that replaces the teleological philosophy of the first half of the nineteenth century by the evolutionary philosophy of the latter half. Our conception of the earth as well as of its inhabitants has been profoundly modified by this revolution, and much of our progress has been conditioned on the full acceptance of the newer view.

Now, if apology is needed for introducing the preceding considerations, which some might call irrelevant, let me urge that whatever share they may make of other sciences, they are also so closely grafted into one or another branch of earth science that we, as geologists or geographers, cannot afford to neglect them. In so far as they are related to elements of our science as consequences are to causes, as responses are to environment, we must take at least some account of them, even if their study in other relations is left to specialists in

other subjects. In doing so, we are only carrying out our work to its legitimate conclusion. It is without question our responsibility to study the ancient inorganic conditions that determined the location and the migration, the development and the extinction of ancient faunas, for these conditions were at least in part geological factors of one kind or another; it is equally our responsibility to study the modern conditions that determine the location of cities and the routes of trade, for these conditions are largely geographical factors; but the examples of organic response here adduced are merely a few of many, and all the rest stand on an equal footing with them, whether they are commonly classed with biology or history, with economics or religion. We long ago saw that the more simple, immediate, and manifest examples of organic, especially of human, responses belonged in the realm of geography; and from this beginning we now realize that there is no stopping-place till we include all other examples, complex, indirect, or obscure as some of them may be; for there is a graded series of connecting examples from the most artful human response down to the most unconscious plant response, and from the immediate responses of today back to the earliest responses of the geological ages.

It would be most arbitrary to draw a division in our studies, when no division exists in the things studied. It is therefore a piece of good fortune that geographers are coming to follow the practice of geologists, and thus to accept among their responsibilities the great breadth of physiographic and ontographic relationships existing today, as geologists have accepted them for the past. And it is also as good fortune that biologists are coming to accept the responsibility of studying environment as well as response; for only in this way have the earth and its inhabitants really learned to know each other. I rejoice therefore whenever a student of earth science completes his studies by carrying them forward to their organic consequences, as seen from the side of the earth; and again, whenever a student of biology, of language, of economics, of religion, carries his studies backward to a consideration of inorganic causes, as seen from the side of life; for thus and thus only we may hope that the knowledge of both causes and consequences shall increase in fulness. Our present understanding of this interdependence, not only of different branches

of our own science, but of the branches of our own and of other sciences, is truly a great step toward the solution of the wonderful riddle of the world.

The real foundation of the broad consideration of earth science rests on the continuity of ordinary processes through the long periods of recorded earth-history. Nothing has so profoundly modified the appreciation of other subjects as well as of our own, as the teaching of geology concerning the conception of time and the long procession of orderly events that has marched through it. Such a conquest of the understanding is enough to make us proud indeed; yet when we realize how short a share of time has been allotted to us, how sincere should be our humility! Today we may be lords of creation, powerful through cephalization; yet in face of the repeated extinction of dominant races in geological history, how can we think otherwise than that we are clad only in a little brief authority; how can we seriously believe that we represent the highest stage, the acme of organic development, comforting and flattering as this deductive opinion may be!

The conception of the continuity of processes, without extra-natural interference, has been forced to fight its way against opposition; now it has gained at least a very general verbal acceptance among us, and is quietly drifting into popular belief. To realize its full meaning is an arduous task, not only because of the opposition of inherited prejudices, but even more because of the inherent difficulty of the problem. To think that processes such as those of today have done all the work of the past is appalling; yet we are constrained to believe it. Even as waves, beaten up in a stormy sea, subside after the winds are calmed, so the mountain waves or wrinkles of the earth's crust, growing as long as orogenic storms are at work, are in time calmed to plains; and this not by unusual processes, but by the patient weathering and washing of scraps and grains. While these slow changes go on in the extinction of mountain systems, the races of plants and animals that originally gained possession of the lofty young mountains, that grew up with them so to speak, must either adjust themselves to the changes in their surroundings, or migrate to other homes, or vanish, all in due order through the flowing current of time.

Nowhere is the orderliness of geological changes better attested than in the forms of ridge and valley seen today in various examples, young and old, of wasting mountain ranges themselves, and in the systematic adjustment that is attained by the drainage lines with respect to the structures on which they work. Here, indeed, is cumulative testimony for uniformitarianism; for nothing but the long persistence of ordinary processes can account for these marvelous commonplaces. So wonderful is the organization of these land and water forms in physiographic maturity and old age, so perfect is their systematic interdependence, that one must grudge the monopoly of the term "organism" for plants and animals, to the exclusion of well-organized forms of land and water. By good fortune, "evolution" is a term of broader meaning; we may share its use with the biologists; and we are glad to replace the violent revolutions of our predecessors with the quiet processes that evolution suggests.

It is the assurance of orderly continuity that binds the past to the present in the endless sequence of events, and shows us that geography is only today's issue of a perpetual journal, whose complete files constitute geology. He must be a geographer of the old school who would now maintain that his subject, in content and treatment, really belongs outside of the geological curriculum. It may, on the other hand, be justly contended that the whole of earth science is made up of geographic sheets—until today, paleogeographic, if you like—all horizontally stratified with respect to the vertical time line. In every sheet we find news of the relation of earth and life, of environing control and organic response, of physiography and ontography. Every little item of news here published is worthy of close attention. The reader may examine all sorts of items on a single sheet and consider their temporary, areal distribution, and so acquire the geographic view; or he may examine the changing items of certain areas, following their chronological sequence in successive sheets, and so acquire the geological view; but it would be unfortunate if, in so doing, he did not perceive the interchangeable relations of these two methods of investigation.

There is, to my understanding, a great profit that has been gained from conceiving the whole body of our science in the way thus suggested. Branches such as meteorology and terrestrial magnetism,

which we ordinarily treat as parts of physical geography and thus associate with present time, are seen really to have their ancient as well as their modern, their geologic as well as their geographic, phases. We can gain some hints as to ancient meteorology, for we find records of paleozoic raindrops, of remote glacial deposits, and we hope yet to find evidence concerning the distribution of early climatic zones. As far as ancient records of this kind can be pieced together, we may study them in their momentary or geographic, as well as in their continuous or geologic, relations. Concerning ancient phases of terrestrial magnetism we are at a loss; yet our conception of even this branch of earth science, as well as that of the meteorological branch, is certainly broadened when it is regarded as a contemporary of all the geological ages, and not merely as a latter-day characteristic of the globe.

Similarly, those geological events which we are accustomed to treat in their time sequence, gain fuller meaning when they are decomposed into their momentary elements, and when each element is treated as a geographical feature associated with its contemporary fellows. The columnar sections of stratified rocks, for example, so useful in the understanding of historical geology, are like the edgewise view of a closed book. The book must be opened, the leaves must be turned over one by one, the pages of these early records must be read, like so many gazetteers of ancient times. Never mind if some pages are worn and others are missing; those that can be still deciphered assure us that the past was generally like the present, and warrant the generalization that geology is like nothing so much as a whole series of geographies.

At the present stage of our progress, the sciences of the earth may be given a somewhat different classification from that of the eight sections into which they are divided for the purposes of this congress. These sections, as it seems to me, represent the subjective divisions of our sciences, within each of which specialists may limit their studies more or less closely, and for each of which speakers may be provided. But when regarded objectively, the divisions, their grouping, and their relative values, must be otherwise presented. Geology objectively considered is not merely one of the earth's sciences; it is the whole of them: it is the universal history of the earth.

It is true that geology has so largely to do with past time that it is not popularly understood to include the present; but it certainly does include the present, and the future also, as fast as it arrives. There is no possibility, in the understanding that we have now gained of earth science, of stopping the geological record at any stage of the Pleistocene, and calling the rest "geography;" that would involve the resurrection of buried theories, which held the past to be unlike the present order of things.

Conversely, geography is stultified when absolutely limited to the things of today, as if the things of the past were of another nature. It is of course popularly so considered, and perhaps for that reason its scientific development is stunted. When regarded objectively, the geography of today is nothing more nor less than a thin section at the top of geology, cut across the grain of time; and all the other thin sections are so much more like the geography of today than they are like anything else, that to call them by another name—except perhaps "paleogeography"—would be adding confusion to the earth's past history instead of bringing order out of it. Our plain duty here is to emphasize the continuity of events, that great result of our studies, and not to imply a break in their succession by using unlike terms for different members of a single series.

Geology thus being composed of a succession of countless geographies, geography, in its widest sense, is likewise composite, including its inorganic and its organic parts. It is particularly concerned with the surface of the earth today, as the home of life; but "surface" and "today" must here be very freely construed; for we must draw upon the sub- and super-surface parts, and on the days before today, whenever we find profit in so doing. When we study the shape and size of the earth, we touch upon what may be developed into geodesy. When we study the inorganic parts of the earth for themselves, in what may be called their static relations, we enter upon mineralogy and petrology, or geochemistry; for it must be remembered that water is a mineral and that air is a rock. When we study the dynamic relations of the inorganic parts of the earth, we have geophysics, within which oceanography and meteorology are subdivisions, of rank similar to terrestrial magnetism and to that large category of phenomena that includes the activities of the earth's crust. It is true

that physical or dynamical geology is the heading under which erosion, volcanoes, and earthquakes are usually treated, as if the present phenomena of the earth's crustal envelope were to be set aside from the present phenomena of the hydrosphere and atmosphere, and associated chiefly with the history of the past. But we have now certainly reached a point when the unity of all these subjects, their interaction in space, and their continuity through time demand their association in a single group of studies which shall embrace all the activities of the earth in their present manifestation; with the full understanding that the present is only the latest addition to the past, and that the past is only the integration of a vast series of ancient presents.

All these present physical activities, even if carried down to such specialties as potamology and kumatology, are so closely associated with the standard subjects of geography that it is difficult and unadvisable to cut them asunder. Yet every one of them may be carried to such a degree of detail as to stand apart, and gain rank as an independent study. The accuracy of the geodesist, the minuteness of the mineralogist, the high flights of the meteorologist have now gone so far in their special development as to lead far away from each other, when they are studied for themselves, however closely their more general results may be associated.

When, however, we study the inorganic features of the earth, not as independent phenomena, but as elements of organic environment, they all belong strictly in physical geography, or physiography. Parenthetically, let me say that I regret the excessive breadth given to this term by British students, and the narrowness imposed upon it by those Americans who would limit it to the study of the lands. When we pursue the subdivisions of physiography, nomenclature becomes incomplete: climatology is unique in being a name for the study of the atmosphere in so far as it determines organic environment; economic geology is a study of useful minerals and rocks, but is less strictly treated as an objective subdivision of physiography than is climatology; and there is associated with it so much of ingenious artifice in the exploitation and treatment of mineral products that we are apt to put the cart before the horse and think that we make gold or coal serve our needs, instead of realizing that we make ingenious

use in money and fuel of the properties that gold and coal possess, just as we make use of moving air in wind-mills and of falling water in factories.

There are no special names for the phenomena of oceans or of the other divisions of physiography, considered as elements of organic environment; and there is perhaps no need of such names. Yet I hold that it is desirable, and even important, to recognize the two ways in which the inorganic features of the earth may be studied: either for themselves, without regard to their controls over organic life; or as elements of an inhabited planet, with continuous attention to the controls that they exert over the inhabitants.

When we come to the organic inhabitants of the earth, it is evident that they fall under biology when studied for themselves, and that they may be divided under botany and zoölogy, and subdivided as often as is desired. This is manifestly true as well of fossils as of living forms. When, on the other hand, the inhabitants of the earth are studied with respect to the responses that they have made to their inorganic or physiographic environment, they are appropriately included under geography. It has been recognized for many years that no geographical description of a region is complete without some account of its plants and animals, and especially of its peoples; just as no paleogeographic account of a geological horizon would be satisfying if its fossil fauna and flora were left unmentioned. But in recent years it has been seen necessary to treat uniformly all the organic elements of geographical descriptions in their relations to environing controls; for, as I have already shown, if a beginning is made, there is no reasonable stopping-place until this end is reached.

We are in this matter still sometimes too much under the control of traditional methods of treatment; we do not fully enough put into practical effect the greater lessons that we have learned. The earth as the home of man is a primitive, elementary definition of geography; the earth as the home of life is more consistent with present progress. Earth science has now certainly reached a position in which the unity and continuity of life are recognized. Let us then adopt this position as our starting-point in the organic half of geography that may be called ontography. Let us make it practically useful by treating all organic responses to environment under one general heading,

even though we afterward find it desirable to treat human responses in a separate chapter. For even if man's will sets him high above the other forms of life, it must not be forgotten that his will often leads him along physiographic lines, and that he possesses many structures and habits entirely independent of his will, and similar to the structures and habits of lower animals as examples of ontographic responses. Even human houses and roads are only different in degree from the houses and roads made by animals of many kinds. Still more, if we accept the principle of the continuity of geography through geology, we must recognize that most of the successive geographies of the past have had nothing to do with the human will, and that man and his works are after all only modern innovations.

The chief impediment to action upon this view, which, as I have said, has been unfolded before us by the progress that our science has already made, is the habit of studying geography and geology too separately, and of regarding the former as a subject for narrative treatment, while the latter is admittedly a subject for scientific investigation. The hint to this effect that is given by the unlike constitution of geographical and geological societies the world over ought not to pass unnoticed. Membership in many geological societies is limited to experts; if membership in a single geographical society is similarly restricted, I have yet to learn of it.

Let us then build on the progress we have made; let us realize that only when ontography is treated as thoroughly as physiography will geographical work gain the best geographical flavor. So empirical has been the traditional geographical treatment of the organic elements, so imperfectly have the organic elements been generally recognized as balancing the inorganic elements in the make-up of the subject as a whole, that no name has come into use for the organic half of geography corresponding to physiography for the inorganic half; and it is to supply this lack that I have elsewhere suggested the name above used. I believe that the adoption of some such name would aid in the systematic cultivation and in the symmetrical development of geography, and thus of geology also as a whole, by bringing more prominently forward the necessity of giving—or at least attempting to give—as scientific a treatment to the inhabitants of a region in their geographic relations as to the region itself.

The adoption of some such term as "ontography" would tend to correct the false idea that geography is concerned only with the elementary and manifest examples of organic responses; it would promote thoroughness of study, and thus more fully continue the progress that we have thus far made. The adoption of the term would, moreover, emphasize the principle of continuity through time—of the geographical stratification of geology, which is of so great importance in the scientific development of our subject; for ontography, in which persistent physiographic influences make themselves felt through inheritance, is then seen to be only the modern member of a great series with whose earlier members we have long been familiar in paleontology. The recognition of the continuity, the essential unity of these two subjects—one dealing with the living forms of today, the other with the dead forms of the past—dignifies the first and vivifies the second; and adds yet another argument in favor of an objective rather than a subjective classification of the sciences of the earth. The beginning of the cultivation of ontography, already made more or less consciously, strongly suggests a larger development for the future. We are thus assured that as the details of organic responses are worked out and the importance of physiographic details is recognized, the difference between physiography as the study of environment, and geochemistry and geophysics as the study of the earth for itself, will diminish. Today no one can say how far the details of these semi-independent sciences may not be found essential in physiography.

Let me now amuse you for a moment with a scheme of terminology that might have a little value if some of its terms were not already appropriated in other meanings. The scheme does not represent the historical development of earth science, but sets forth its several parts in the relations that our progress up to date shows them to stand.

Suppose we should use the ending *-ology* to denote the conception of sequence in time, and *-ography* to denote the conception of temporary distribution. We should then have our whole subject, geology, in which time sequence is the dominant idea, made up, like an endless prism of mica, of an indefinite number of momentary sheets of geography that cleave across the time axis. Biography would then lose its

limitation to man, and become the study of temporary floras and faunas in successive geographies; while biology would give up its usual meaning and become the study of life in the developmental sequence of organic evolution through geological time. The study of the minerals and rocks of any epoch would be minerography and petrography, while mineralogy and petrology would treat problems of paragenesis and metamorphism in which the passage of time is essential; and for one, I should then be able to remember what petrography and petrology mean. So we might go on with physiology, meteorology, and oceanology as made up of a succession of physiographies, meteorographies, and oceanographies, and we should have glaciology and climatology made up of glaciography and climatography; and ontology or the sequence of organic responses to the changing earth, would be made up of a succession of ontographies.

Schemes of terminology, however, are not often successfully made to order in this fashion; they are slowly evolved without much regard to system, as is seen in the haphazard nomenclature of oceans, seas, gulfs, and bays. Minerography is strange to the point of offense to the ear; we cannot take over biography and physiology from their present uses; we must get along with the terms that we have, and with such new ones as are added from time to time. My only object in suggesting this fanciful scheme is to bring more clearly forward the space- and time-relations that are recognizable in all branches of our subject, as well as in geography and geology. The progress of the last century has certainly brought us now to a stage when these general relationships may be in good part understood, if we give heed to them. We fail to take the best advantage of our progress if we see only the specialized development of our several subsciences.

It has often seemed to me as if petrologists were rather overwhelmed at present with the flood of new facts that modern methods of research have let loose upon them; yet how greatly is the study of both mineralogy and petrography broadened by the addition of the continuous to the momentary consideration of minerals and rocks that the flood has swept before us; for even the rocks have their phases of youth and age. So brief is our life that geomorphologists are even today hardly accustomed to the systematic mobilization of land forms; yet the description of the lands is greatly strengthened when their forms

are seen to be fixed only in the sense that an express train seems to be fixed before the instantaneous wink of a camera's eye. The ontographer may be bewildered when he realizes what the evolutionary struggle for existence means to the individual; and when he thinks how long the world was the scene of relentless strife before pity was born, and how young and impotent pity is still, we may well wonder whether we have yet learned much of omnipotence. Yet how superb is the conception of the procession of life, never halting in its march through the corridors of time.

The addresses of the eight sections into which the department of earth science is divided will so fully consider the special problems with which we are concerned that it has seemed best here to deal only with a few general considerations. I have therefore sought to consider only the prospect from the point of view to which the progress of a hundred years has led us. Vast as is the expanse over which we look, innumerable as are the elements of the view, the chief impression that we gain is one of well-ordered interaction in the continuous progress of events, all of whose momentary geographic phases, with all their parts of earth, air, water, and responding life, are spread upon successive pages in the great volume of geological records.

W. M. Davis.

Cambridge, Mass.

NOTICE OF SOME NEW REPTILES FROM THE UPPER TRIAS OF WYOMING.

THE University of Chicago paleontological expedition to Wyoming the past summer was fortunate in securing a valuable collection of stegocephalian and reptilian remains from the Trias, a part of which is described in the present paper.

The beds whence the fossils were obtained, from forty to eighty feet in thickness, are about two hundred feet below the top of the red-beds and about six hundred feet above their base. Their description will be given in a later paper by Mr. N. H. Brown, their discoverer, and the writer. Meanwhile the horizon may be distinguished by the name Popo Agie[1] beds, as suggested by Mr. Brown, from the Popo Agie River, along whose branches they are most characteristically shown.

Dolichobrachium gracile, gen. et sp. nov.

Coraco-scapula (Fig. 1).—Scapula elongate, flattened, directed backward nearly parallel with the long axis of the body; the blade elongate, moderately thickened, and of nearly equal width throughout; back of the middle of the lower margin, there is a slight angular projection. Anteriorly the bone curves sharply downward to the glenoid fossa, at right angles to the shaft, and has a free, thin, rounded margin in front. The upper margin of the glenoid fossa is thick, prominent, and rounded, supported by a strong thickening of the bone above it; in front this thickening has a heavy, rounded margin standing out prominently from the thinned anterior plate of the scapula. The fossa has no rim in front, the surface blending into the non-articular sloping surface extending to the thin front margin of the bone. Nor is there a rim behind, but below the border is very prominent, more so than the upper border, though thinner, the bone being excavated below it to form an obliquely projecting rim. Coracoid elongate antero-posteriorly, the anterior part directed strongly inward; the posterior margin nearly on the same plane as the glenoid fossa and

[1] Pronounced *popo azhie*, or, in the vernacular, *popózhie*.

the inferior border of the shaft of the scapula. The anterior part of the coracoid, though preserved, has not yet been fitted to the remainder of the bone; it is rather thick, and seems to have been directed strongly inward. No traces of a supracoracoid foramen, nor of any connecting sutures are visible in the united bones.

Humerus (Fig. 2).—The left humerus, found associated with its corresponding coraco-scapula, is a remarkable bone. The head is thickened, the shaft curved forward and compressed, the condyles have a long articular sweep and are obliquely placed. The dorsal surface proximally is convex from side to side below the slightly prominent head, the lateral or deltoid process forming a long, backwardly curved margin. On the palmar side the surface is concave, and the head is more prominent, the slightly convex articular surface looking mesad and ventrad.

FIG. 1.—Left coraco-scapula of *Dolichobrachium gracile*.

The shaft, distad to the lower end of the deltoid process, is strongly compressed from side to side, with a considerable convexity in front. The condyles stand far backward, the inner one more prominent and slightly longer than the outer one. They are also obliquely placed, so that, when resting on a plane, the plane of the upper part is not more than thirty degrees from the vertical.

The external condyle extends through nearly three-fourths of a circle; the trochlear groove is deep and narrow. On the outer side, a little above the end, there is a thickened, rounded projection, partially separated from the shaft by a groove; it perhaps corresponds to the supinator ridge. The bone has no internal cavity.

In addition to the bones described above, the specimen as collected comprises a number of ventral ribs and a large part, perhaps the larger part, of the skull. The latter, however, is badly shattered from exposure, and will require much patient labor to restore it. In much probability other bones of the skeleton remain to be excavated, and it is hoped to secure them the coming summer.

FIG. 2.— Left humerus of *Dolichobrachium gracile.*

The specimen was discovered by Mr. Roy Moodie and Mr. E. E. Ball.

What the relations of this animal are it is at present impossible to say, other than it probably belongs to the early rhynchocephaloid type, or in the super-order Diaptosauria of Osborn. I can find nothing in the literature, of either the Permian or Triassic reptiles of Europe or America, which approaches it. The structure of the girdle, the shape of the humerus, and its mode of articulation indicate a swift-moving crawling reptile of considerable size. The skull will doubtless throw much light on the affinities and habits of the animal. I hope to present a discussion of this part of the skeleton within a few months.

Height of glenoid fossa	120 mm
Antero-posterior extent of same	102
Width of coracoid below rim of glenoid fossa	120
Width of scapula above rim of glenoid	152
Antero-posterior expanse of scapula	460
Width of blade of scapula	108
Length of humerus	445
Greatest width, upper end	147
Width of shaft, lower third	44

Eubrachiosaurus browni, gen. et sp. nov.

Left humerus (Fig. 3).—Head, when seen from above, elongate oval or semilunate, the posterior border strongly convex. Tuberosity (median process of Fürbringer, teretial process of Owen) separated by a narrow and constricted depression from the capitular

border; expanded below, the gently convex surface looking ventrad and mesad, extending a little less than a third of the length of the bone. Below this process, on the inner border, there is a small convexity, which may, perhaps, represent the tricipital process. Inner ventral surface above deeply concave; bounded above and on the side by the margin of the capitular projection and that of the median process. Lateral (deltopectoral) crest elongate and thickened, very protuberant, extending a little more than one-half the length of the bone (ten inches), directed obliquely outward and ventrad; outer margin convex, but produced into an obtuse angle below, the thickness somewhat greater below. In the specimen this process has been slightly crushed dorsad. Posterior surface proximally gently convex, concave on the outer side, with the rounded head strongly protuberant. Shaft below lateral crest much constricted, its conjugate diameters being nearly equal. Entepicondylar canal directed nearly downward, the flattened bridge over it being the continuation of the lower margin of the lateral crest. Entepicondyle thickened and roughened for muscular attachment; ectepicondylar or supinator ridge broad, arising as high up as the upper margin of the external opening of the epicondylar canal, and nearly as high as the lower end of the lateral crest, its border nearly semicircular in outline, gently curved forward. Olecranal fossa large, shallow, triangular, nearly flat. Radial articular capitular surface large, convex, forming a small, rounded process on the dorsal side and a large one on the ventral side. Ulnar articular surface smaller, but extending nearly as far ventrad, the intervening trochlear groove rather deep and narrow.

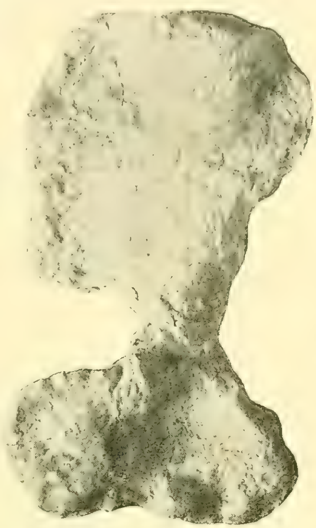

FIG. 3.—Left humerus of *Eubrachiosaurus browni*.

Scapula.—An elongate bone, presenting the essential characteristics of a dicynodont scapula, was found lying with its distal end impressed upon the inner side of the ilium, and close by the humerus

above described. Its size and slenderness seem disproportionate to the massiveness of the humerus, but that it belongs with the pelvis and humerus there can be scarcely a shadow of doubt. It has a thickened articular end below, a part of which is missing—that which protruded from the face of the cliff and led to the discovery of the specimen. Doubtless there was another facet here for the coracoid. The upper part is expanded and flattened, with the anterior border thickened, the inner surface somewhat concave. This thickened anterior part is continued into an elevated ridge on the dorsal side, which ends rather abruptly near the lower extremity—the acromion.

FIG. 4.—Left innominate bone of *Eubrachiosaurus browni.*

Pelvis (Fig. 4).—The bones which, because of their shape, must belong to the left side of the pelvis, from the position in which they were found and from certain peculiarities of their shape, were first thought to belong with the pectoral girdle, and it was not until the specimen had been nearly completely reconstructed that its real nature was apparent. The most remarkably dilated and elongated anterior part of the ilium, had it not been so strongly curved, would rather represent the blade of the scapula, and no articular surfaces for the attachment of the sacral ribs have been detected—there are certainly none such low down on the bone.

The united ischium and pubis were slightly separated from the ilium on the left side, and entirely so on the right side. The connecting surfaces were so incrusted with the tenaciously adhering matrix that their sutural nature is not apparent, though without doubt the separation took place at the suture, since the united ischium and pubis of the opposite side have the same shape.

The ilium extends upward and forward in a broad curve. The upper portion is broad, flat, and rather thin. The distal part had been broken off before fossilization, and the attaching fracture so corroded and incrusted with matrix, removable with difficulty from the thin bone, that its precise relations are somewhat doubtful. This portion has been omitted in the photograph, but the free, thin, concave border seems to continue the curve before it for about eight inches, the distal portion being somewhat dilated and very thin. Such a shape is most extraordinary for an ilium. This part of the ilium turns outward as though for the protection of the abdominal walls. The posterior border of the ilium was unfortunately lost before the presence of the bone was suspected, lying as it did below the scapula. It was evidently thin.

The acetabulum forms a deep oval cavity, somewhat notched at the upper posterior part. The pubis was directed obliquely inward, and has a strong, everted, articular face, perhaps for an epipubis or prepubis, very much as has been figured in species of dicynodonts.[1] A little in front of the middle, and about two inches below the rim of the acetabulum, there is seen a short, free margin, evidently the upper margin of the thyroid (obturator) foramen, and in all probability situated in the line of the suture between the pubis and ischium, since both bones were broken apart in this same place. The border connecting the pubic and ischiadic angles has not yet been reconstructed, but patient labor will doubtless fit in the whole of this portion from the many thin fragments preserved in each of the specimens.

The pubis and ischium are turned inward toward the median line.

Lying upon the distal part of the humerus there was a small bone, about six inches in length, which seems to be a sacral rib, resembling as it does the corresponding bones of some dinosaurs.

Length of humerus	440 mm
Greatest width across lateral process	237
Breadth, lower end of lateral process	182
Least diameter of shaft	68
Greatest width, distal end	263

[1] *Tapinocephalus*, Lydekker, *Catalogue of Fossil Reptiles*, British Museum, IV, 82.

Length of scapula	444
Least width, a little above acromion process	63
Greatest width	213
Thickness of glenoid articulation	55
Height of ilium	650
Diameters of glenoid fossa	140, 160
Expanse of ischio-pubis	320
Length of pubis from rim of acetabulum	145
Length of ischium from rim of acetabulum	200
Width of blade of ilium	170

The specimen above described was found protruding from a face of the cliff near the uppermost part of the Popo Agie beds, in the vicinity of the Little Popo Agie River, by Mr. Roy Moodie and the writer. The specimen was partly worked out by myself, and later by Mr. Branson and Mr. Moodie. The great difficulties under which the specimen was secured prevented at the time exploration for other bones. There can be little doubt but that other parts of the skeleton, perhaps the larger portion, still remain in the rocks, and, it is hoped, will be secured another season.

What the relations of *Eubrachiosaurus* are with other reptiles it is yet impossible to say with much degree of certainty. I do not believe that the genus belongs with the Pareiasauria, chiefly because of the presence of an entepicondylar foramen, though the humerus resembles that of *Pareiasaurus* somewhat. The humerus recalls that of *Platypodosaurus*, but, upon the whole, I believe that the animal will be found to be nearest related to *Tapinocephalus* or *Phocosaurus*, from the Karoo beds of South Africa. The ilium is incompletely known in these genera, but the size of the acetabulum, the shape and structure of the ischio-pubis, the posterior projection of the ilium and the limited sacral attachment, all point to that genus. At all events, I believe that the genus, as also *Placerias* Lucas, and the following, belong among the true Anomodontia. From *Placerias* Lucas,[1] from the Trias of Arizona, this form differs very evidently in the great expansion of the lower end, the ectepicondyle, which is figured in *Placerias* as convex and thick, being widely expanded.

Brachybrachium brevipes, gen. et sp. nov.

A single humerus, though incomplete, found near the upper part of the Popo Agie beds, and in almost identically the same horizon as

[1] *Proceedings of the U. S. National Museum*, 1904, p. 194.

that of the preceding genus, shows such decided differences, and, moreover, is so characteristic, that I venture to describe and name it. The upper extremity is thin and narrow; probably some portion of this had been lost prior to fossilization, but inasmuch as Broom describes this extremity in *Udenodon* as narrow, I believe that little is missing. The thick and massive lateral process is directed upward. The inner condyle is rounded below, showing that nearly the whole length of the bone is present, though the outer condyle, that projecting from the face of the cliff, is wanting. The large entepicondylar canal begins considerably above the lower angle of the lateral process, and not wholly below the process, as in *Eubrachiosaurus*. The bridge covering it is very stout. The median process is small, not protuberant and flattened, as in the last genus. The outer border is concave from above downward, strongly convex transversely. At the lower end of the part preserved the border becomes thinner, but it is not possible that there was any such supinator expansion as is shown in *Eubrachiosaurus;* if any, it was situated much more distad. The condyles must have been remarkably broad, equal to much more than half the length of the bone, and the olecranal fossa is large and deep. The upper part of the palmar surface of the ulnar process is preserved, and is much more massive and prominent than in *Eubrachiosaurus*. If the radial prominence was relatively as large, it must have been very massive.

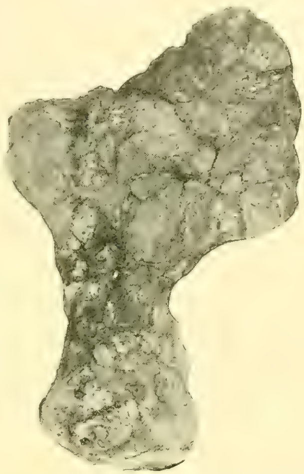

FIG. 5.—Left humerus of *Brachybrachium brevipes*.

The specimen was discovered by Mr. Roy Moodie, and removed from the very hard sandstone by him and the writer.

Length of the bone as preserved	255 mm
Width across lateral process	197
Estimated width of condyles	200
Least diameter of shaft in plane of condyles	70

Paleorhinus bransoni, gen. et sp. nov.

(Fig. 6).—A new genus of phytosaurs, somewhat more primitive than any hitherto made known, though agreeing rather better with *Belodon* than *Phytosaurus*, is represented in the collection by a nearly perfect skull in excellent condition. The genus is especially characterized by the more anterior position of the external nares, their nonseparation by the nasal bones, and by the more lateral position of the orbits. The accompanying outline figure of the side of the specimen will show the positions of the various openings better than they can be described. Some of the sutures have not yet been determined. The external nares are at the extremity of a nose-like protuberance, the openings looking partly upward, partly forward

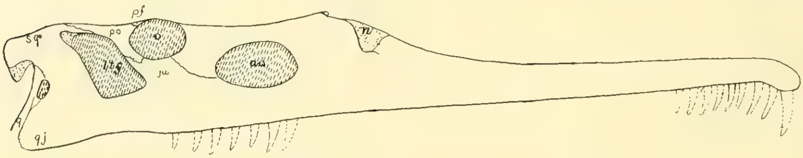

FIG. 6.—Skull of *Paleorhinus bransoni*.

and outward, separated by two, thin, vertical plates, perhaps the mesethmoids. The ontorbital opening is elongate oval in shape, and situated between the orbits and nares. The anterior part of the beak is turned downward, as in *Phytosaurus*, and has a single large tooth on each side. The posterior end of the mandible is shaped much as it is figured in *Mystriosuchus* by Fraas, that is with a very small angular projection situated low down. The front end of the mandible is missing.

Length of skull - - - - - - - -	735 mm
Length from tip of beak to nares - - - -	390
Length to front end of orbits - - - - -	565
Width between orbits - - - - - -	42
Width of skull posteriorly (about) - - - -	190

From *Typothorax* Cope and *Episcoposaurus* Cope, based upon fragments, the form is evidently different. From *Heterodontosuchus* Lucas, from the Trias of Utah, based upon the anterior end of the mandible, I cannot state the differences with assurance. The only available character given for that genus is the proximity of the

teeth, since all the teeth had fallen from the sockets in this specimen. The teeth are not separated by an extremely thin partition, but have quite an interval between them, in some cases equal to the diameter of the sockets. I feel more confidence in the distinction, however, from the fact that another genus in the collection has the teeth much more closely placed.

Another form, represented by a complete skull of larger size, in the collection, has the anterior nares apparently placed much further forward than in the present genus, or at least the beginning of the slender beak is much further forward. Yet another skull, of large size and nearly complete, has been nearly freed from its matrix. It measures 960 mm in length; the nares are not as far forward as is the front end of the ontorbital opening, though more anteriorly placed than in *B. scolopax* Cope, and the strongly deflected anterior end of the beak has three large teeth on each side. The hind teeth are flattened and serrate. Still another skull seems different from any of the foregoing.

S. W. Williston.

PLEISTOCENE GEOLOGY OF THE SAWATCH RANGE, NEAR LEADVILLE, COLO.

THE writers, as students of geology in the University of Chicago, spent two months of the past summer in studying the glacial geology about Leadville, Colo. It is their plan to continue the work next summer. The work was carried on under the direction of Professor R. D. Salisbury, who was with the writers for a week toward the close of the season's work.

So far as known, little detailed work on the Pleistocene geology of the region had been done. The maps of the Hayden Survey mark certain areas as being morainic, and Mr. S. F. Emmons, in his monograph,[1] mentions briefly the effects of glaciation in this area; but otherwise little seems to have been published.

The work of the past summer was mainly on the east slope of the Sawatch Range. It covered all the area on the Leadville quadrangle of the U. S. Geological Survey, which lay to the west of the Arkansas River, the Tennessee Fork, and the Eagle River.

TOPOGRAPHY

The chief topographic features of the region are the two great parallel north-south mountain ranges, the Sawatch Range on the west, and the Park Range on the east. The higher peaks of both rise to heights of more than 14,000 feet. In the trough between these ranges are the Arkansas and Eagle Rivers. The former flows south, and the latter north. These rivers are fed by large numbers of tributaries from the slopes to the east and west, most of the tributary valleys being almost at right angles to the valley of the main stream.

GLACIATION

The area studied is about 350 square miles in extent. Of this, 275 square miles show definite effects of glaciation. It is probable that, at the maximum, the ice covered a somewhat larger area. The drift is referable to at least two distinct epochs of markedly different

[1] *Monograph XV*, U. S. Geological Survey, pp. 41–44.

age, with possibilities of a third epoch much earlier than the two whose results are well marked.

EXTENT OF ICE

The last glacial epoch.—The ice of the last glacial epoch covers by far the larger part of the surface of the mountains proper. The ice came down all the larger valleys tributary to the main valley, and in most cases only the narrow crests of the ridges between the side valleys projected above the glaciers. In several instances the glaciers of the side valleys descended to the present position of the river in the main valley, and in a few cases they crossed the main valley to the base of the opposing range. Of the entire area west of the great north and south valley about three-fourths was covered by the ice of the last glacial epoch, and a large part of the unglaciated one-fourth lies beyond the foot of the mountains proper.

Ten distinct systems of glaciers of some importance were studied in this area, besides four cliff glaciers of small size. Of the ten more important systems three extended barely to the foot of the mountains. Seven got well out into the wide valley, east of the mountains, and five of them extended to the present position of the river, and the same number extended below the 9,000-foot contour.

The glaciers varied in length from one to twenty miles, and in area from one-third of a square mile to about eighty square miles. The Lake Creek system was longest, and also greatest in area. Of the very small glaciers, one started at an elevation of 11,000 feet, but an elevation of about 12,000 feet seems to have been necessary to start glaciation in most places. The glaciers all originated in similar situations. Their sources were in cirques which lay back toward the higher parts of the mountains. The ice from these cirques, moving downward, merged in each of the principal mountain valleys, and developed a tongue of ice which advanced far down the valleys. About sixty separate cirques contributed to the ten large glaciers of the region.

In all the larger glaciers the ice had a thickness of over 1,000 feet, while in the valleys of Homestake and Roche Moutonnée Creeks the thickness exceeded 2,000 feet.

The drift.—The character of the glacial deposits varies greatly in

topographic form and physical constitution, with the character of the surface upon which the deposits were laid down, and with the material which the ice had to handle. In the Evergreen Lakes glacier, for example, the drift has a characteristically new appearance, both in respect to its materials and its topography. The material of the drift of the Lake Fork glacier, on the other hand, looks very old. There are few large bowlders at the surface, and most of the rock material in the drift is notably decayed. But the topography of even this moraine is new, and it was, without question, contemporaneous with the newer appearing drift of the Evergreen Lakes moraines.

The difference in the material in these two cases is to be explained by the difference in the condition of the rocks over which the two glaciers moved. Even now the bed-rock in the upper part of the valley of Lake Fork is deeply decayed, showing that the glacier did not clean out even all the decayed rock. The upper part of the area out of which the Evergreen Lakes glacier moved is of hard fresh rock, showing that the ice of the glacier removed not only all decayed rock, but also some of the fresh rock beneath. The freshness of the drift deposited by this glacier shows that much undecayed rock was worn away by the ice.

The glaciers terminated in two classes of situations, and their terminal deposits stand in a somewhat definite relation to the position of the ends of the glacier. The ice in the valleys of Homestake and Rock Creeks, and in the valley west of Mitchell, never reached a Piedmont plain upon which they could deploy, but ended in the narrow mountain valleys. Under these conditions there was no opportunity for the terminal deposits to accumulate in great terminal moraines, since the abundant water from the melting ice carried the drift away about as fast as the ice left it. No terminal moraines of consequence occur at the ends of these glaciers.

The other larger glaciers of this region sent their ice beyond the confines of the narrow valleys, and deployed to some extent on the valley plain beyond, building great terminal moraines. These two types of termini and of terminal accumulations are well shown by the glaciers of Homestake Creek, on the one hand, and those of Lake Fork, Clear Creek, and Half Moon Creek, on the other. The absence

of terminal moraines in the former case has been noted. In glaciers of the Lake Fork type, the ice deployed on the plain at the base of the mountains, and enormous quantities of drift were piled up in the form of terminal moraines. The terminal moraines often have abrupt outer faces, 200 to 300 feet high, and are marked by a characteristically irregular, hummocky topography.

The terminal moraines are continuous with and merge into the lateral moraines in the mountain valleys. The lateral moraines are often large and lie against the valley walls, their crests sloping down the valley. The crests of the lateral moraines are over 700 feet above the stream in some parts of the valley of Clear Creek, and descend with an even slope of 200 to 400 feet a mile down the valley. Beyond the mountains, the lateral moraines tend to flatten out, and merge into extensive terminal moraines.

Little detailed work was done on the glaciation of the Park Range, but it is known that ice of the last glacial epoch occurred in the "gulches" east and southeast of Leadville; in the valleys of the East Fork of the Arkansas River, Ten-mile Creek, and over a considerable portion of the east slope of the Park Range.

The older drift.—In a number of places within the area studied there are tracts covered with scattered bowlders or bodies of drift, which are certainly of glacial origin, but which are much older than the drift of the last ice epoch. In these patches the present topography is due to erosion, all signs of kettles, or irregular hummocks, having disappeared. The rock outcrops have generally been weathered into sharp crags, a change which certainly required much more time than has elapsed since the last glacial epoch. The surface bowlders, too, are often weathered considerably, crumbling to pieces under the hammer.

The evidence that this drift is glacial is found along several lines. The bowlders are of a size which would militate against a fluvial origin. Striæ are sometimes found on the under, unweathered surfaces of the bowlders, or on the faces of those in fresh cuts in the drift. The distribution is such as would be expected from older and more extensive glaciers, for the drift in question occurs just outside the new drift, or above it on benches to which the last ice did not reach. The patchiness of the old drift is due largely to

erosion since its deposition. In one or two instances the older drift shows something of the lateral moraine ridge form, outside and above the newer lateral moraines, but more often it occurs in thin sheets, or merely as scattered bowlders.

Possibility of a still earlier epoch of glaciation.—Certain facts point to the possibility of a still earlier epoch of glaciation in this region. Two miles above Granite, on the east side of the Arkansas River, bowlders were found 200 feet above the river, which seem to have come from the Sawatch Mountains. These bowlders are rather rare, and are much weathered, although of very resistant granite.[1] The position of these bowlders beyond the limits of the ice of both well-determined epochs of glaciation points to a possible

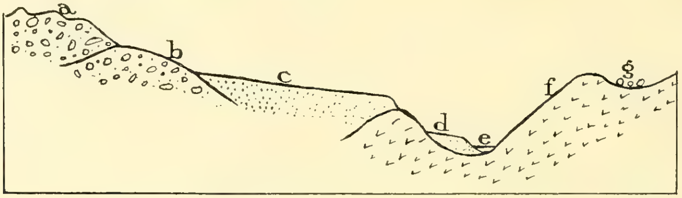

FIG. 1.—A generalized section across the valley of the Arkansas, to illustrate the conditions in the vicinity of Granite.

a, terminal moraine of last epoch from a side valley; *b*, moraine of older drift; *c*, high terrace lying against older drift; *d*, low terrace corresponding in age to *a*; *e*, Arkansas River; *f*, granite into which river has cut a post-older glacial channel; *g*, bowlders from mountains on opposite side of valley, which appear to be older than *b*.

period of glaciation older than either, the drift of which has been almost entirely removed. The evidence, however, does not seem to be altogether conclusive. Some other bits of evidence of like import are found at other points, but they have not been sufficiently developed to make their significance certain.

The general relations of the two sheets of drift to each other, and of both to the valley gravels, and to the scattered bowlders of still greater age, are shown in Fig. 1.

TERRACES

High terraces.—A most striking feature of this region is the great display of terraces, seen at their best on the east side of the Arkansas River, south of Leadville. These terraces rise with abrupt faces

[1] These bowlders were found by Mr. L. F. Westgate, before the writers visited this side of the valley.

above the river flat, and slope upward toward the base of the mountain at an angle of 2–4°. They have plane surfaces and uniform slopes, and, although deeply cut by erosion, are evidently remnants of a plain which sloped somewhat continuously from the base of the mountains on either side of the valley to an axial trough somewhere near the middle of the valley.

In constitution these terraces are composed of well-rounded, water-worn gravels, coarser toward the base of the mountains and up the Arkansas valley, and finer away from the mountains and down the valley. In general, the gravels in any particular place seem to correspond to the rocks found in the mountains just above. For the most part these beds are uncemented, although locally the gravels have been cemented into a friable conglomerate by lime carbonate.

Mr. Emmons, in his monograph on the Leadville district,[1] refers to the terrace deposits as being of lacustrine origin, and argues that the slope of the terraces away from the mountains is due to subsequent tilting. The correspondence in the slope of the terraces on the two sides of the valley, and the lack of any observed deformation in the beds, do not seem to favor the view that the beds have been tilted since deposition, while the coarseness and the imperfect stratification of the gravels, and the absence of any observable delta stuctures, seems to the writers to make the Lake Bed hypothesis untenable. Although locally there may have been small lakes in which deposits of gravel were laid down, by far the greatest portion of these deposits are referable to river work. With this hypothesis the slope of the terraces is in harmony. These deposits must at one time have been considerably more extensive than now, for the Arkansas River has cut a very considerable valley in the former plain of aggradation.

For the construction of the plains from which these terraces were developed there must have been a great amount of detritus supplied to the streams. In following the high terraces from the river to the mountains on either side we found in the three places which were most carefully studied, that their upper edges were in contact with bodies of older drift. The earlier glaciers, of considerably greater size than the later ones, may have supplied great quantities of débris to the

[1] *Monograph XII*, U. S. Geological Survey, pp. 41, 71, 72.

swollen streams, and might well have caused the formation of the plain from which these terraces were subsequently developed by erosion. Somewhat careful search fails to show glacial striæ on the stones of the gravel, but striæ were hardly to be expected even if the gravels be of fluvio-glacial origin.

Another fact which seems to favor the glacio-fluvial origin of these terraces is found in the relation of the Twin Lakes and Clear Creek moraines to the valley. At the time of the last glaciation the ice from the west pushed across, or nearly across, the Arkansas valley at these places, and must have blocked the valley to some extent. Now, the older drift shows that during the earlier glacial epoch the ice was even more extensive, and must also have obstructed the valley at these points. This would have given the main stream a lower gradient, if it did not dam it altogether, and so favored the deposition of the gravels above. If the valley was effectually dammed, lakes would have existed; but the main body of gravel does not appear to have been deposited while this condition existed, if it existed at all. Furthermore, it is not apparent that the dam could have been high enough at any time to hold the water up to the level of the high terraces.

That the high terraces are of great age is plainly shown by the oxidized and decayed condition of their materials, as seen in a number of fresh sections, especially about Malta. Again, the small streams from the mountains have cut valleys deep into the terraces, valleys which are much larger than those cut by similar streams in the late glacial drift.

Low terraces.—Outside of, and below, the high-terrace level there sometimes occurs a set of low terraces which bear the same relation to the last glacial moraines as the high terraces do to the older drift. They connect with the new moraines at their upper ends, and their materials are of the same lithological character as those found in the new drift. The physical condition of the material of these terraces corresponds to that of the new drift, and they have suffered an amount of erosion comparable to that which has effected the new moraines. The few available sections in the low terraces fail to show any striated stones, although plainly formed from the outwash of the new drift.

The relations of the low terraces to the new drift and of the high

terraces to the older drift seem to be analogous, and point strongly to the glacio-fluvial origin of both sets of terraces.

CHANGES IN DRAINAGE AFFECTED BY GLACIATION

Two clear cases of changes in drainage due to glaciation were worked out in this region. The Eagle River, one and a half miles below Pando (Fig. 2, *a*) enters a narrow rock gorge, about three miles

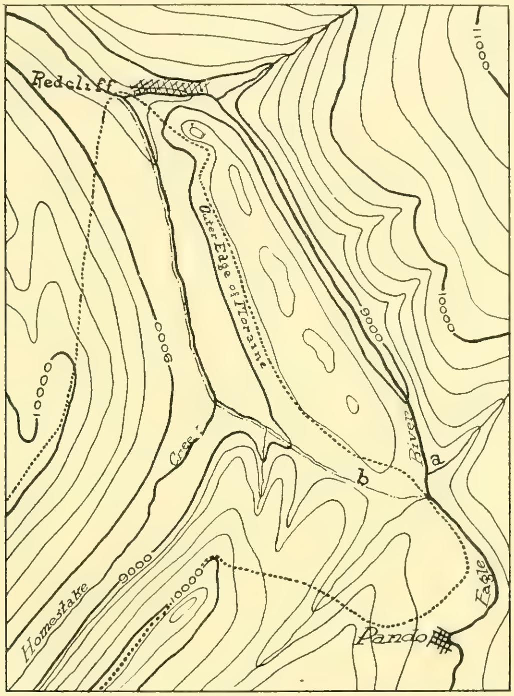

FIG. 2.—Sketch map of an area of about seventeen square miles near Pando.

a represents the head of the postglacial rock gorge entered by Eagle River a mile below Pando; *b* indicates the position of the probable preglacial course of the Eagle River. The dotted line represents the position of the moraine of the glacier which came down Homestake Creek.

long. In this gorge, the stream, although of considerable size, has cut itself only a shallow valley, which is clearly very young. Just west of the point where the stream leaves its broad valley for the narrow gorge, there is a low, broad, col (Fig. 2, *b*), filled with drift, beyond which lies Homestake Creek, which has, from this point down, a much larger valley than its size would require.

The history of the change seems to be as follows: As the ice of the last glacial epoch came down the valley of Homestake Creek, it pushed across the valley then occupied by the Eagle (Fig. 2, *b*) and by obstructing the stream, ponded it, and caused it to find a new outlet to the north. On the retreat of the ice, a drift dam was left across the old valley, and the Eagle continued to occupy its new channel as far as Redcliff, where it re-enters its old valley.

The second case is that of the Arkansas River,[1] the course of which was changed by the ice of the earlier (next before last) epoch of glaciation. The ice, advancing down the valleys of Lake and Clear Creeks, pushed across the Arkansas valley to the slope on the east side, and crowded the river up against the granite walls on that side, and even shifted it up somewhat on the other slope (see Fig. 1). At these places the river cut a new channel in the rock. From data gathered from borings at the placer mines west of Granite, it appears that the surface of the rock declines to the west for a considerable distance west of Granite (Fig. 1), indicating that the preglacial channel of the river was some distance west of the present river bed between Twin Lakes and Clear Creek. The river, being pushed over to the east at two points, may have had, at first, a great loop to the west between these points. If so, the curve may have been cut out and the channel straightened by piracy, or it may have been crowded over between the ice lobes, by fluvio-glacial deposition.

S. R. Capps.
E. D. K. Leffingwell.

The University of Chicago.

[1] Professor L. F. Westgate, of Ohio Wesleyan University, was working upon this problem when the writers entered this portion of the field, and it is understood that he will publish his results on this problem in the near future. He had worked out the essential features of the changes in the channel of the Arkansas before the writers reached this part of their field.

THREE NEW PHYSIOGRAPHIC TERMS.

CERTAIN phases or types of topography, some of them widespread and all of them distinct, have no appropriate designation. Reference to them, where they have been recognized, has been by tedious circumlocution. Names for three such phases or types of topography are here proposed.

I. TOPOGRAPHIC UNCONFORMITY.

The essential idea underlying this term is a topography on the upper part of a slope, which is out of harmony with the topography on the lower part of the same slope. The slope may be that of a mountain, a hill, or a valley, or it may be the slope of a larger tract, such as a coastal slope. The lack of harmony may be brought about in various ways. The term has to do with the result, not the process by which it was brought about. Two illustrations are added.

1. When a mountain valley, the slopes of which are well dissected by rain and river erosion, is occupied by a thick and effective glacier, the ice is likely to obliterate many of the erosion features of the valley slopes, up to the limit of effective ice-action. The obliteration of the erosion features of the lower slopes is effected partly by erosion and partly by deposition. The result is that the more open, broad, and mature erosion features of the upper slopes are interrupted below at the upper limit of effective ice-action. The more open valleys and ravines above are continued below by the young, narrow, gorge-like drainage channels developed since the glaciation of the valley. These drainage lines of the lower slope are out of harmony with the drainage lines above. In such cases the topography above the limit of effective glaciation is in *unconformity* with that below. Topographic unconformity of this type is common in the western mountains. It may be seen, for example, about Telluride, Colorado, on the slopes above Lake Chelan, and in scores of other places. Fig. 1 shows a portion of the west slope of Lake Chelan near the south end. The topographic unconformity resulting directly from glaciation is somewhat overshadowed by the topographic unconform-

ity which resulted from the development of shore terraces in a lake which stood much higher than the present lake after the ice melted.

2. If a coastal region affected by well-developed valleys is submerged, the lower ends of the valleys become bays. Shore deposits may be made across the mouths of the bays, converting them into lagoons. The lagoons may then be silted up. If the region be subsequently elevated relative to sea-level, the streams coming down

FIG. 1.—The slope of Lake Chelan, showing topographic unconformity.

the mature valleys above cut new valleys across the new lands recently emerged. The result is that valleys and topography of greater or less maturity above are succeeded coast-ward by valleys and topography which are much younger. Fig. 2, from the coast of California, affords an illustration.

It is, of course, clear that the same sequence of events may affect a lakeshore, where it is clearly the level of the water which fluctuates. Illustrations of topographic unconformity are perhaps more readily drawn from lakeshores than from seacoasts, for notable changes of water-level are here more common. The borders of Lake Chelan, already referred to, furnish a good illustration, and the shores of

Lake Bonneville furnish others. (See Plates I, IX, XXI, XXII, XXVI, and XXVII, *Monograph* I, U. S. Geological Survey.)

In general, it may be said that any cause which brings about the relations indicated above—namely, greater topographic age on the

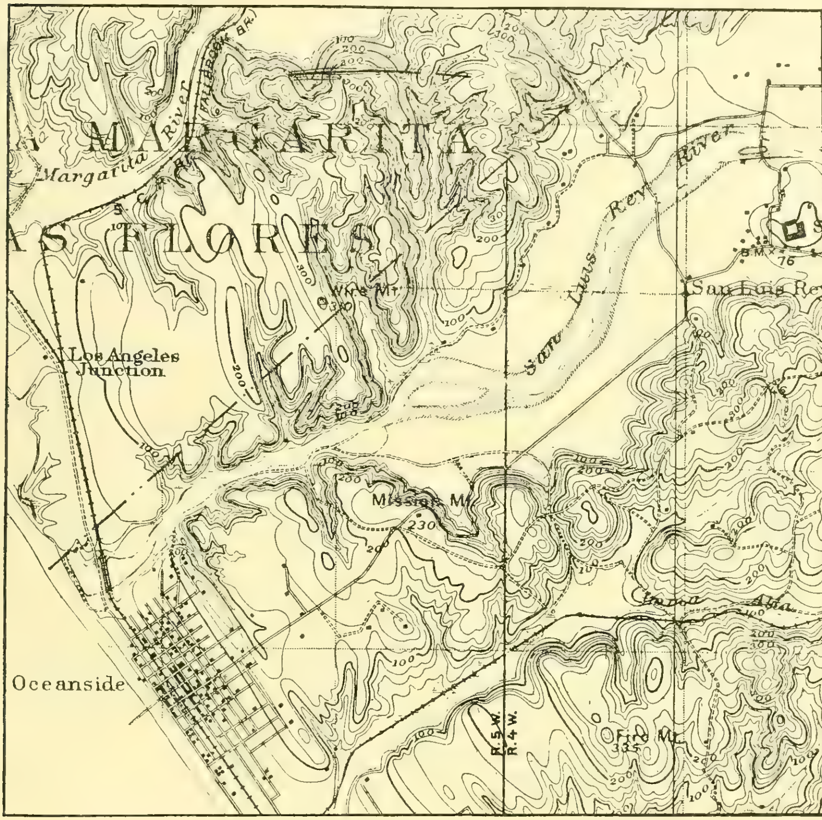

FIG. 2.—Topographic unconformity shown in contours, Oceanside, Cal., quadrangle. Scale, about one and one-fourth miles to the inch.

upper part of a slope, and lesser topographic age on the lower part of the same slope, with a distinct line or belt of separation between the two—develops *topographic unconformity*. If the relations were reversed, so that lesser age on the upper part of a slope was succeeded by greater age below, the two phases of topography being separated by a distinct line or zone, the result would also be a topographic

unconformity. This case is less common than the other, and, on the whole, less striking, since lesser age above and greater age below is the rule. In the normal case, however, there is no distinct line or zone of separation.

Another phase of topographic unconformity will be referred to under "Superimposed Youth."

II. TOPOGRAPHIC ADJUSTMENT.[1]

The term "adjustment," as applied to streams, has been long in use. A stream is said to be adjusted when it flows as little as possible on resistant formations, and as much as possible on weak ones. In general, adjusted streams follow the strike of the formations over which they run, and where they depart from it they are likely to do so by flowing with the dip for short distances. It is proposed to designate the above type of adjustment *structural adjustment.* Structural adjustment has to do with the courses of streams.

There is another type of adjustment, namely, *topographic adjustment*, which has to do with the profiles of streams. One or two illustrations will suffice to make the meaning of the term clear.

1. When a stream has a wide flood-plain, its channel is likely to be now against one bluff, now against the other. This is true of different parts of the valley at the same time, and of the same part at different times. When a stream flows against the bluff on one side for a considerable period of time, the tributaries adjust themselves *topographically* to this position of their main; that is, the lower end of each tributary has the same elevation as its main at the point of union, and the grade of the tributary above the junction is the grade normal to the stream. If now the main stream shifts to the opposite side of its valley, the tributary stream is thrown out of topographic adjustment. Its lower end is too low, for, essentially without grade, it must find its way across the wide flood-plain to the channel on the other side. The result is that the tributary aggrades its lower course until it has a proper gradient out to its main. When this is accomplished, *topographic adjustment* is established.

If now the main stream swings back again to the bluff which it temporarily abandoned, the tributary finds itself again out of topo-

[1] This term has already been published: CHAMBERLIN AND SALISBURY, *Geology: Processes and Their Results.*

graphic adjustment. Its lower end is now too high, and it sets to work to deepen its lower course. When the lower end of its channel is brought to the level of the main at the point of junction, and when its profile above is in harmony with the deepened lower end, the stream is again in topographic adjustment.

2. When falls recede past the debouchures of tributaries, the tributaries are no longer in topographic adjustment to their main.

3. The hanging valleys of glaciated mountain regions, and waterfalls are other cases of lack of topographic adjustment, or of non-adjustment.

Any other course of events which brings about similar results—and they may be brought about in several other ways—may be said to result in the topographic non-adjustment of streams.

III. SUPERIMPOSED YOUTH.

The terms "youth," "maturity," "old age," etc., as applied to rivers, are now in common use. There are certain phases of youth, however, which the term "youth," as commonly used, does not seem to define. In many parts of North America, for example, the topography was mature and the relief great when the ice of the glacial period came on. Partly by erosion and partly by deposition, the ice effected changes in the topography. As the ice retreated, drainage re-established itself on the modified surface.

It often happened in such cases that the old valleys were partially filled, without being obliterated. They were often filled deeply at some points, while they received little drift at others. Basins were developed, and in many cases these basins became the sites of lakes. The drainage which established itself in such regions after the ice melted has not in general had time to obliterate these marks of topographic youth, especially within the area of the last ice-sheet. The streams and valleys themselves have many of the characteristics of youth, such as falls, rapids, lakes at high levels, and, locally, narrow postglacial gorges. All this may be true while the mature topography of the underlying rock is but faintly masked. Considering only the greater features of the topography, there is the appearance of maturity; but when the minor features, such as lakes, ponds, marshes, falls, narrow postglacial gorges, and the peculiar uneroded,

or little eroded, topography of the drift are considered, youthful features are seen to abound. In such cases, *youth* has been *superimposed* upon maturity. It is proposed to call this phase of youth

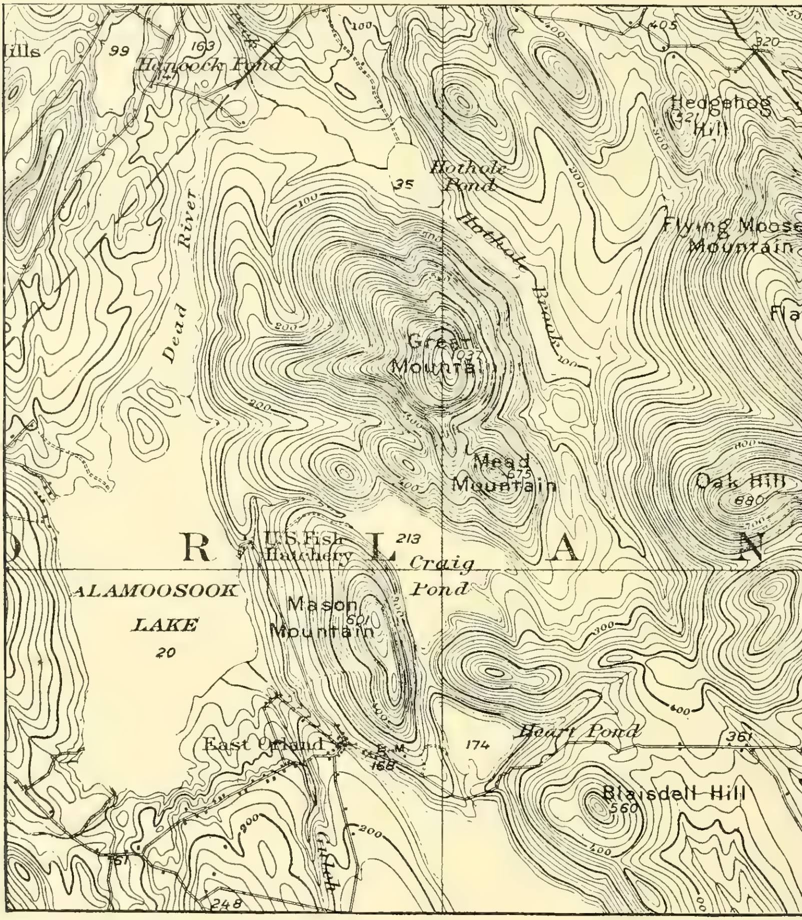

FIG. 3.—Superimposed youth, from the Orland, Me., quadrangle. Scale, about one and one-fourth miles to the inch.

superimposed youth. Fig. 3 furnishes an illustration. Good illustrations abound in the glaciated mountains of the East, and in many areas farther west.

In the foregoing case, youth was superimposed on maturity.

But the type of youth here referred to might be superimposed on a topography which was old, or on a topography which was young. Thus, when the upper, but not the lower, portion of a young mountain valley is severely glaciated, a topographic change is effected. The wide, open, U-shaped or cirque-like upper part of the valley which was glaciated, is often continuous below with a narrow valley of a very different type. In spite of the fact that the glaciated part of the valley is wide open, it possesses distinctly youthful characteristics. Even though the valley was youthful before glaciation, its youth has now assumed another phase. Here youth is superimposed on youth. Examples of this phase of superimposed youth abound in nearly every mountain range of the West where there were glaciers during the last epoch.

In the cases cited, the superimposition of youth has resulted from glaciation. Should it become desirable to distinguish between the youthfulness superimposed by different means, the type of superimposition cited above might be called *glacially superimposed youth.*

Between the *superimposed youth* of the upper glaciated part of the valleys cited in the above illustration, and the normal youth of the parts below, there are (1) a *topographic unconformity* and, (2) a lack of *topographic adjustment.*

THE NEED OF DISCRIMINATING TYPES OF YOUTH.

There are various types of topographic youth which need to be discriminated. Take, for example, the types of youth illustrated by the region about Fargo, N. D. (Fig. 4), and that shown along the shore of Lake Michigan just north of Chicago (Fig. 5). The former region has often been cited, and properly, as an illustration of topographic youth, but it hardly represents normal youth.

The different phases of youth shown by these two areas are always confusing to students at the stage when they are learning to interpret topographic maps. In the one case, young valleys are in process of normal development, and those which continue to grow should, in the course of time, acquire permanent streams. In the other, the surface came into possession of a well-developed stream somewhat suddenly, after the retreat of the ice. The meandering

course of the river, in the one case (Fig. 4), is often mistaken for a mark of age.

Special names for the types of youth illustrated by these two

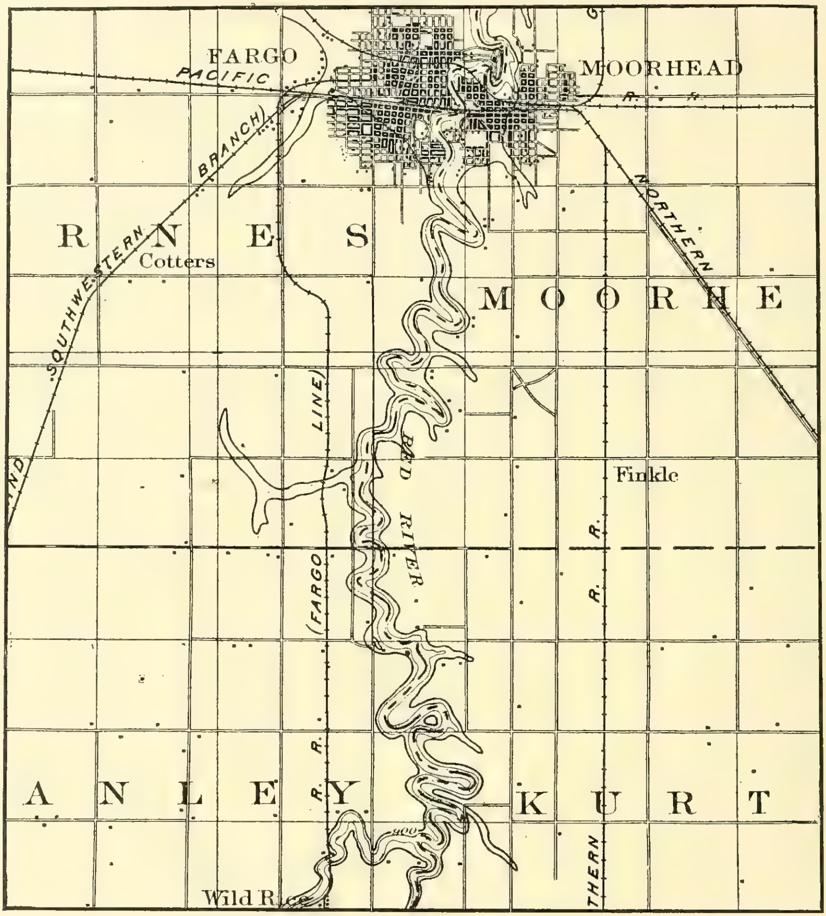

FIG. 4.—A type of youthful topography, from the Fargo, N. D., to Minnesota quadrangle. Scale, about two miles to the inch.

areas would be useful. If the type of topography represented in Fig. 5 be regarded as that of normal youth, that shown in Fig. 4 should be designated by some qualifying adjective. No fitting

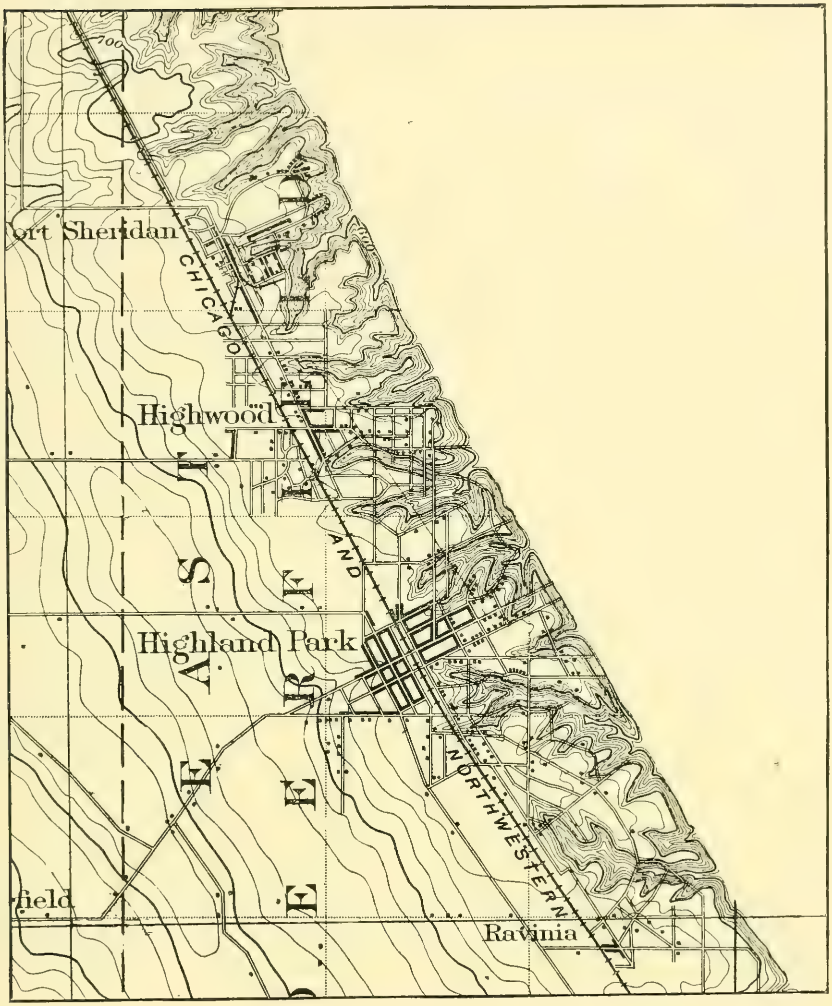

FIG. 5.—A second type of youthful topography, from the Highwood, Ill., quadrangle. Scale, about a mile to the inch.

term has suggested itself. *Superimposed youth* hardly seems to be appropriate, for there is here no evidence, which the student who is not yet a master of topographic maps may recognize, that the stream has been superimposed.

ROLLIN D. SALISBURY.

ON CERTAIN ASPECTS OF THE LOESS[1] OF SOUTHWESTERN IOWA.

Recently the Chicago, Burlington & Quincy Railroad has made some extensive cuttings on a new right of way in southwestern Iowa, affording thereby excellent opportunities for observations on the loess and the underlying till. These cuts are especially interesting on account of the varied aspects presented by the surface material overlying the glacial drift. Three sheets of loess in the same vertical section are discernible.

First, or uppermost, is the ordinary yellow deposit of the Missouri bluffs phase common at the surface everywhere throughout the region, and which needs no further description.

Underlying this loess is a loess of different character; it is whitish in color, and is more clay-like in texture than the ordinary deposit. It appears also to contain less calcareous matter. The white loess and the yellow loess are distinguishable, not merely in fresh section by their difference in color and texture, but also in weathered exposures by their different aspects. The yellow loess tends to assume that peculiar facies familiar to all who have seen the western phase of the loess, whereas the white loess displays more of the behavior of a joint clay, especially as regards superficial drying and cracking.

Below the white loess and in marked contrast with it in the matter of color is a red loess. This red loess occasionally contains a few calcareous nodules of the general appearance of loess kindchen; its lowermost six inches contain pebbles of various sorts, but these rarely exceed the size of a bean and are absent from the upper part of the deposit, as they also are from the white and the yellow loess. In texture the red loess resembles somewhat the white loess above it; it is apparently a little less clayey.

[1] It may not be out of place to remark that there seems to be a tendency to give the word "loess" a specific meaning rather than to assign to it a generic significance, which would be more desirable. To the writer loess means any considerable accumulation of surface material, eolian in origin, the component particles of which are too small to give the deposit the character of sand or grit. Subject to this limitation, loess may have any texture or any color, as well as any peculiarity of topographic facies.

Underneath the red loess is the pebbly till of the Kansan drift-sheet, which is here of the same general character as that everywhere seen throughout southern Iowa. It is the usual rock meal charged with erratics of every description; the uppermost three or four feet present the usual aspects of the ferretto zone so well described by the geologists of the Iowa survey. The color of this ferretto approximates closely that of the red loess above it, but there is never the slightest difficulty in distinguishing the line of demarkation. The leaching

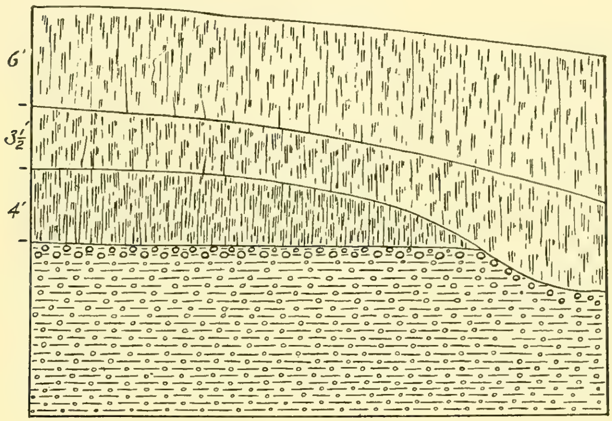

FIG. 1.—Section in railroad cut at Red Oak, Iowa, showing the three deposits of loess over the Kansan till.

and oxidation which produced the ferretto have left it mottled with white patches of kaolin, marking the site of former pebbles of feldspar. It contains also numerous pebbles of quartzite, greenstone, and other materials. Moreover, the exact line of demarkation is very frequently indicated by a layer of gravel and pebbles which owes its origin to the action of wind and weather on the long-exposed surface of the till, whereby the finer particles were removed and the coarser ones left behind as a mechanical concentrate. This phenomenon is similar to that observed at the contact of the upper surface of the Iowan drift with the loess in the paha region of the eastern part of the state.

As shown in the railroad cuts within the city limits of Red Oak,

the yellow loess, is, at a maximum, about twelve feet in thickness, the white loess about six, and the red about four or five. Westward of Red Oak both the red and the yellow loess increase in thickness relatively to the white loess, which finally disappears in this direction. The yellow loess then rests directly on the red loess. To the eastward of Red Oak the reverse is true; the yellow and the red both decrease in thickness. In a sixty-foot cut two miles east of Red Oak the red loess is wanting; the white loess, eight feet in thickness, rests directly on the ferretto. Near the Adams county line the yellow loess appears to be very much reduced. East of Corning the surface loess resembles the white loess and may be identical with it; the resemblance here imputed refers both to fresh and weathered sections.

The most favorable place for studying these deposits and the relations between them are: in the cut just east of the depot at Red Oak, south of the depot in the bluffs left in excavations made by the railroad for material for fills, and in the cuts on the divide between the East Nishnabotna River and Walnut Creek.

As regards the propriety of designating the white and red deposits herein described as loess, there can be little question. They are deposits of loess for practically the same reasons that have been urged in the case of the yellow loess, the eolian origin of which has now been conceded by most geologists. Like the yellow loess, they conform, blanket fashion, to the inequalities of the pre-loessial topography; like the yellow loess, they are invariably thickest on the crests and brows of the erosional hills carved out of the old Kansan drift-plain. They are not to be considered as of subaqueous origin for the reason that no conclusive evidence has been obtained that the region in which they are found was ever submerged beneath such a large body of water as would have been a condition necessary to their deposition.

The red loess is evidently no mere local deposit. It has been observed in Pottawattamie county, which lies north of Montgomery county, by Udden,[1] who describes it under the name of "gumbo."

[1] *Iowa Geological Survey*, Vol. XI, p. 255. The writer has examined the red deposit described by Udden as occurring under the yellow loess at Minden, and has satisfied himself of its loessial nature as herein defined. It may be remarked that the name "gumbo," as applied to the red loess, is apt to prove a confusing misuse of a

The reddish-yellow loess reported[1] by Udden from Mills county is probably a modification of the red loess; the ferruginous, weather-stained loess reported by Calvin[2] as occurring in Page county under the yellow loess, and separated from it by a layer of cross-bedded eolian sand, can scarcely be anything else. The white loess will probably be found to have a wide distribution; it, or a loess very much like it, is to be found under the yellow loess in Carroll county.[3] Bain and Tilton[4] have casually mentioned the occurrence of two sheets of loess at different points in southern Iowa. One of these is probably the white loess. The white loess is also reported from Pottawattamie county by Udden, who, however, thought it to be a modification of his gumbo. As the width of the area of overlap of these two sheets of loess appears to be rather limited, Udden probably did not see them in the same vertical section, and hence his failure to recognize them as distinct deposits would be accounted for. A very interesting suggestion is contained in the fact noted above, namely, that the red loess does not seem to extend far to the east of Red Oak, while the white loess apparently thins out to the west of the same place. The suggestion is that a deposit of loess may have fairly definite boundaries, which may be imposed on it by vegetation in much the same way as vegetation imposes limits to the spread of the drifting sand of a dune area.

The red, the white, and the yellow loess are not different phases of one original loess which has undergone secondary modification since its deposition. A view affirming the contrary would be negatived by the reflection that changes produced by weathering or interstitial deposition of material by infiltration would not be likely to simulate

term borrowed from agricultural terminology. "Gumbo" properly means a stiff, impervious, waxy, clay-silt, which the red loess certainly is not. It is an open question whether the red loess was deposited as such, or acquired its red color through subsequent oxidation of its iron content. On the other hand, there exists the possibility that it consists of the finer particles sorted out of the red ferretto and carried by the wind to new resting-places. It would therefore be local in origin; the other loesses are, however, clearly foreign.

[1] *Ibid.*, Vol. XII, p. 167.

[2] *Ibid.*, Vol. XIII, p. 445.

[3] Verbal communication from Professor B. Shimek, and later verified by personal inspection. Both sheets of loess are well shown in the railroad cuts southwest of Carroll.

[4] *Op. cit.*, Vol. VII, p. 523.

ordinary bedding over wide areas. Conclusive evidence that each is a deposit *sui generis* is also afforded by their stratigraphic relations; all three deposits must be regarded as unconformable the one with the other as well as with the till. This is beautifully shown as regards the red and the white loess in the cut just east of the depot at Red Oak, where it may be seen that the red loess has been involved in erosion antedating the white loess, which fills a depression previously cut through the red loess into the till. Analogous evidences of a stratigraphic break between the white and the yellow loess are not wanting in the same neighborhood. In this connection the red loess observed by Calvin in Page county may again be referred to. The layer of eolian sand there separating the red loess from the yellow loess is additional, if slight, evidence of the time break between the two deposits.

The inferences to be drawn from the existence of these three sheets of loess and from their mutual relations are extremely interesting. Considered along with the cursory references of various geologists to the existence of distinct loess sheets in southern Iowa, it would appear that the real complexity of the loess can no longer be doubted; "the problem of the loess" becomes, in a new sense, one of magnitude and importance. Here, as elsewhere in geology, a stratigraphic break is a fact of prime significance. The deeply scored surface of the Kansan drift is clear evidence of a long period of time before new conditions brought on the red loess; the supercession of red loess deposition by an interval of erosion, followed by a period which witnessed the deposition of a new and different loess, is sufficient evidence that the interloessial period was long enough to bring about fundamental changes in governing geological conditions. The change from the white to the yellow loess has the same significance.

It may be permissible to remark that the development of our knowledge of the loess is perhaps now in about the same stage as was our knowledge of glacial drift just after its glacial origin had been established. At first geologists could see only one drift-sheet and did not dream of more than one ice-invasion. It was only after the complexity of the glacial deposits had been perceived that they were forced to those studies which have given us our present theories of glacia-

tion. It remains to be seen whether a general recognition of the complexity of the loess is to be followed by a satisfactory explanation of the loessial and interloessial stages. Iowa, which has become classic ground for the glaciologists, will undoubtedly afford much illuminating material to the students of the loess.

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THE EFFECT OF SUPERGLACIAL DÉBRIS ON THE ADVANCE AND RETREAT OF SOME CANADIAN GLACIERS.

Observations on rates of motion, amounts of advance or retreat of glaciers, and kindred statistics are now being collected from all quarters of the globe in the hope of deducing some general laws of ice-motion in the present, and of throwing some light on glacial conditions in the past.[1]

Obviously the advance of glaciers is influenced by two factors: (1) rate of motion, and (2) rate of waste. Any cause increasing the rate of motion will tend to push the front of the ice forward, and this advance will be held in check only by the amount of waste. Waste will be increased either by a rise in temperature, producing increased melting and evaporation, or by increased exposure to dry air producing evaporation. A glacier may advance, therefore, either from increased motion or from decreased waste.

Observations on the advance or retreat of existing glaciers have been correlated almost exclusively with the factors influencing rate of motion. The rate of waste is usually neglected, or is regarded as of secondary importance. Of secondary importance it may be in the case of any one glacier, since the daily and annual ranges in temperature about the freezing-point are approximately the same in successive years. Hence it may be safely assumed that the amount of water lost by any one glacier will differ from year to year mainly in proportion to changes in the mass of the ice, which in turn is affected by rate of motion. But when different glaciers are compared, it becomes evident that rate of waste is an important factor in determining the position of the ice-front.

Glaciers differ from each other in rate of waste, as they do in rate of motion, and a sluggish glacier, slow-moving and slow-wasting, may advance farther than one whose rate of motion is faster, but whose rate of waste is also faster.

[1] Harry Fielding Reid, Journal of Geology, 1895 to date.

The several factors influencing the rate of melting will be discussed later. The one which it is especially desired to emphasize is the protective effect of a thick covering of débris.

It is a familiar fact that dust absorbs the sun's heat, causing melting, with the formation of dust wells, while larger fragments shade the ice, and may be left standing on protected pillars, the ice having melted around them. Sand and débris cones are formed in the same way, from the shading of the ice by a pile of material. Obviously, if this process were carried to an extreme, and the entire surface of the ice covered, the whole would be shaded, and hence protected from melting.

In regions where glaciers now occur (i. e., regions of high altitude or of high latitude) there are great contrasts in temperature between sun and shade. It frequently happens that this contrast involves a range above and below 32°, and that the temperature is below freezing in the shade when it is well above in the sun. A débris covering will protect a glacier from the direct sunlight, and may therefore keep its temperature below 32°, and so prevent melting.

Moreover, the daily range in temperature at the surface of the soil is much greater than the daily range slightly below the surface. A point below the surface will be shielded from extremes and will be colder during hot, and warmer during cold, hours, than the surface. In the case of glaciers, a débris covering protects the ice from the air of the surface. Hence in times of extreme cold the protected ice will be warmer than the surrounding air; in times of heat it will be colder. Since in regions where glaciers now exist, the yearly temperatures below 32° are greater in number and in amount than those above, this protection from the air will be of more avail to prevent melting than to cause it.

It is therefore to be expected that protected glaciers should advance farther down their valleys than if not so protected, and that the retreat of protected glaciers would be slower.

In the mountain region of British Columbia and Alberta there are many hundred existing glaciers. This region is one of especial interest to the glacialist in that it appears to be the center from which came the lobes of a large part of the Cordilleran ice-sheet. The highest parts of the mountains were never covered by ice, nor

does there seem to have been formerly any common direction of movement. In the past, as at present, glaciers moved toward all points of the compass, and the present glaciers may be regarded as the actual remnants of the upper portions of the great glaciers of the past.

The Canadian Pacific Railway affords easy access to many of these glaciers. It crosses the mountains near the fiftieth parallel, and at this point the glaciers are confined to a belt about one hundred miles wide, within the Rocky and Selkirk ranges.

The valley glaciers near the line of the Canadian Pacific may be classified into two groups. These groups are primarily geographical, being respectively east and west of the continental watershed, but the glaciers of these two groups have striking physical differences also.

GLACIERS OF THE CENTRAL AND EASTERN ROCKIES

The valley glaciers of this region have little or no névé portions, being fed by avalanches from overhanging cliff glaciers. These avalanches carry down great quantities of bowlders, mixed with the ice and snow, with the result that glaciers of this type are covered throughout almost their entire length with a thick mantle of débris. The cliff glaciers have névé portions, but the topography is such that large snow-fields do not accumulate. The cliff glaciers rest on exceedingly steep slopes, usually terminating upward in arêtes, so there is little place for the accumulation of snow. It is characteristic of this region that its glaciers consist of an upper névé and cliff portion with very high gradient, separated by a fall from a lower débris-covered valley portion.

GLACIERS OF THE WESTERN ROCKIES AND SELKIRKS

These glaciers have very large snow-field and névé regions, and such material as they carry is largely subglacial or englacial. In their method of formation these glaciers resemble the typical valley glaciers of Switzerland, but differ in that they are proportionally broader and shorter. In this region one névé may feed many glaciers, whereas to the east many cliff glaciers feed a single valley glacier.

Of late years Messrs. George and William S. Vaux[1] have recorded

[1] George and William S. Vaux, "Observations on Glaciers in British Columbia," *Proceedings of the Academy of Natural Science*, Philadelphia, 1899.

observations on the Illecillewaet, or great glacier of the Selkirks. Their observations include a measurement of the rate of motion of different parts of the ice by means of iron plates fixed on the surface, and also a record of the retreat of the ice front since 1887. They record a few observations on other glaciers, but these are of a more general character. In 1888 Dr. William S. Green made a single measurement of the rate of movement of the Illecillewaet.[1]

These observations appear to be the only ones on record. In the face of such sparse statistics, generalizations seem premature;

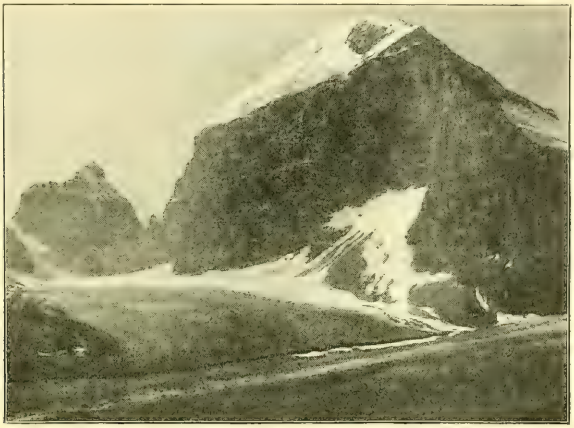

FIG. 1.—Victoria Glacier, showing level surface, and cliff glaciers on Mount Lefroy.

nevertheless, one fact is evident, namely, that the glaciers on the east, which are covered with débris, are either advancing or retreating slowly, while those on the west, with clean surfaces, are retreating rapidly.

GLACIERS OF THE FIRST GROUP

Victoria glacier (*Fig. 1*).—This glacier is now well known to tourists, lying at a short distance from one of the Canadian Pacific Railway châlets, and being the feeder of the now famous Lake Louise. As seen on the map (Fig. 2), it is short and wide, and has two branches, which come from the south and the east repectively. These branches are fed by avalanches from the cliff glaciers of

[1] GREEN, *Among the Selkirk Glaciers* (Macmillan, 1890).

Mounts Victoria, Lefroy, and Aberdeen, and except in its upper portions, the glacier is covered with débris. The glacier is nearly flat, and each of its upper ends entirely fills its valley. Snow and rock from avalanches form a heterogeneous pile on the surface, snow predominating at the ends and the sides of the upper portions. This snow is rapidly melted by the heat of the sun, and a short distance from the upper ends is a region of small ice pillars. As the lower end is approached, surface débris increases, until at the extreme

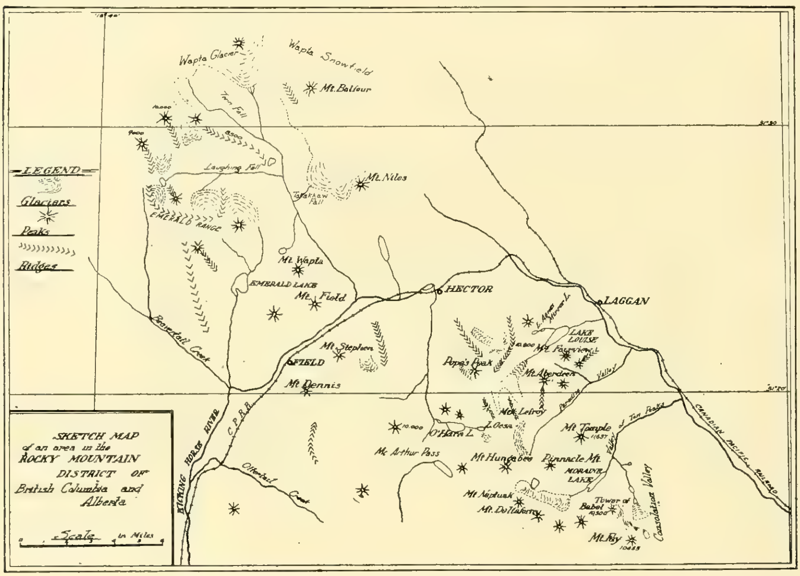

FIG. 2.—Sketch map of area referred to in text.

end it is in most places impossible to tell where the ice ends and moraine begins.

In recent geological time this glacier was evidently of much greater extent, but in the immediate past it extended only a short distance farther than at present. It has left a series of recessional moraines, but these are close together, often crossing or ramifying. Closely bordering this recessional belt are fair-sized trees, and beyond these trees no moraine is found. Glacial material is abundant throughout the valley, but beyond the moraines it is in a secondary position, deposited by water. Of late, therefore, the glacier has retreated but little.

It is a notable fact that the Victoria glacier does not face directly down its valley, but diagonally across it, the ice-front facing the northwest. The high cliffs of Aberdeen keep off the early morning sun, so that even in midsummer the sun does not strike the glacier before 7:30 A. M., and then at first only the northwest side. The direction faced by the ice-front is thus determined, not by the direction of motion, but by the position of maximum melting.

As already stated, the end of the ice is mainly buried in moraine, but at two points ice is exposed. At both points the face is steep,

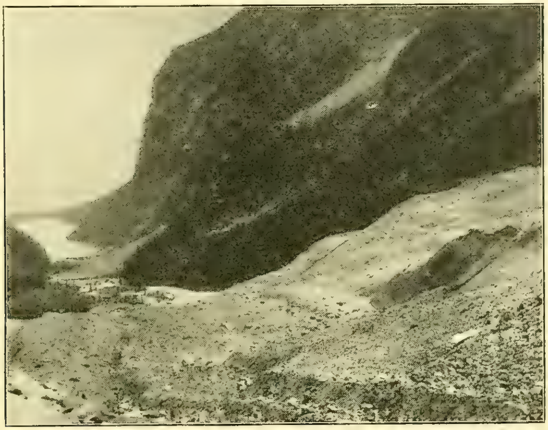

FIG. 3.—Front of Victoria glacier, showing its steep face, diagonal position in the valley, and terminal moraine.

exposing the laminæ of ice. In this respect it resembles high-latitude glaciers, rather than the usual alpine type (Fig. 3).

The surface of the Victoria glacier is very flat, the angle of profile rarely exceeding 8°. This flat surface makes an angle with the steep front somewhat exceeding a right angle.

During the year from July, 1899, to July, 1900, Mr. Vaux found that a marked bowlder in a central position on the ice moved 147 feet. One at the edge moved 115 feet. Shrinkage for the year was only 6 feet.

Glacier of the valley of the Ten Peaks.—This glacier occupies a valley parallel to that of the Victoria glacier, some ten miles to the southeast. Moraine Lake lies in this valley a short distance below

the glacier, the glacier itself being confined to the southeastern side of the upper end of the valley. This glacier closely resembles the Victoria, but has a few points of difference. The cliff glaciers which feed it are on the southeastern side of the valley. Opposite these cliff glaciers, on the northern side, are talus-covered slopes. The talus also apparently occupies a portion of the valley bottom, and here meets some old and very angular débris. A small lake occupies the valley bottom at an elevation of about 7,000 feet. It is surrounded by talus and débris on three sides, the fourth being the rock of Mount Pinnacle. This lake appears to be fed by a sub-talus inlet, the greater part of its water coming from the side of the glacier. This glacier, then, is fed not only at its end, but from its southern side, and water issues not only at its front, but at points along the northern side.

Its surface is covered with débris more deeply than that of the Victoria glacier. The rock masses are remarkably angular and often of great size. In several places piles of débris have accumulated, protecting the ice beneath and forming rock cones.

This glacier is remarkable in that it is advancing, both down the valley and also laterally on its northern side. For the lower mile of its course it is now overriding a large forest. Unfortunately, no data are on record concerning its rate of advance or its rate of motion.

In a pamphlet on glaciers Mr. Vaux remarks concerning this glacier: "At some date, not very remote, an unusual avalanche of rocks of enormous proportions has buried the ice deep in piles of huge stones and bowlders which, preventing the access of the sun's rays, protect it from much melting." It is hardly necessary to postulate an *unusual* avalanche. The cliffs south of the glacier are tremendous, and the rock, a thick-bedded limestone, weathers along its joint planes into large rectangular blocks which are continually falling to the glacier below. In this weathering process not only the cliff glaciers, but also gravity and the great daily range in temperature, are effective.

The fact that the glacier fills only the southern part of its valley seems due to the same cause that leads to the diagonal fronting of the Victoria glacier. The ice is shaded by high cliffs on the east and

south, and when the morning sun finally strikes it, the first portion to be touched is the northern side. This glacier also has little fall, and its front is steep. Its valley is terraced and shows evidence of occupation by a great glacier in the past, and Moraine Lake is held up by a débris dam; but there are no modern terminal moraines other than the one now being formed. This glacier, therefore, is larger at present than at any very recent time. It is a significant fact that this glacier, which is advancing, should be much more deeply covered with débris than other similar ones which are retreating slightly.

FIG. 4.—Front of glacier in Consolation Valley, showing its steep face, and terminal moraine in the lake.

Glacier in Consolation Valley.—Consolation Valley is the largest tributary of the valley of the Ten Peaks. It is similar to the two preceding valleys in the presence of lakes in the lower part of its course, and of a débris-covered glacier at its head. This glacier seems to be little visited, and was omitted entirely from the Canadian survey map (Lake Louise sheet, 1902).

The trend of the valley is northward; consequently the glacier is not shaded in the early morning. As a result, it faces directly down its valley. At its upper (southern) end this glacier begins in two alluvial cones which meet from opposite sides of the valley. It is fed mainly from its southwestern end and side, from cliff glaciers on Mount Fay (Fig. 4). Cliffs bound its southwestern side, and from these cliffs several alluvial cones extend, in some cases reaching the ice and loading it with material. The consequence is that the glacier is streaked with ridges of material of various kinds and colors, according to the source. These ridges bear a general resemblance to

medial moraines. Between the ridges the ice is comparatively clean and has melted so that the débris stands up on ridges of ice.

A remarkable feature of this glacier is the presence of several lakes on the ice. Their basins apparently began as transverse crevasses, and grew by melting. Their walls are vertical, and display the synclinal structure of the ice, with the drift covering on the surface. There are several lakes in various stages of growth, the process being that of melting away beneath, the top being shaded by débris, and the result being the production of a nearly round lake from a long narrow one. The largest of these lakes measured about 500 feet by 300 feet.

FIG. 5.—Lake on the ice of the glacier in Consolation Valley, showing the synclinal structure of the ice and the débris covering.

Débris was constantly falling into this lake. The layers of ice could be plainly seen (Fig. 4). The lamination was due mainly to differences in consistency of the ice. The amount of interbedded material was small, but was all concentrated along definite layers.

The lower end of this glacier was more completely covered with débris than the upper part, the streaks of different colors being pushed close together. The glacier ends in a lake, a nearly perpendicular cliff of ice rising from the water. Here also the layer of ice may be seen (Figs. 5 and 6).

One recessional moraine is present, extending in a peninsula from the shore of the lake into the water. On the shore the northern edge of this moraine is bordered with bushes, and there are no other recent moraines. It is therefore evident that this glacier is only a few feet shorter than at the time of its recent maximum extension.

Features common to the preceding glaciers.—These glaciers each have a main line of drainage coming from beneath an arch of ice, but only a portion of the drainage comes directly into this channel. Water escapes through the bordering débris at the front and sides, and can often be heard trickling beneath the drift. The subglacial drainage of the Victoria glacier has been changed, a long cave showing the position of a former exit. No superglacial drainage was observed.

It is characteristic of all of these glaciers that their gradients are

FIG. 6.—Glacier in Consolation Valley.

low; that their centers are but slightly higher than their sides; that their fronts are nearly vertical; and that of late they have retreated little, if at all. The cliff glaciers which feed them are 2,500 feet or more above the level of the valley glaciers below, and the lower limit of the glaciers is at about 6,000 feet.

The material with which their surfaces are covered is angular and talus-like. It is frequently stated that superglacial material is highly oxidized, and that by this characteristic it may be distinguished from subglacial material in the deposits of the glacial epoch.

Among the glaciers of the eastern Canadian Rockies the superglacial material accumulates by falling on the ice in steep, narrow valleys, as in the instances just described. In no case was the amount of oxidation found to be extensive. It was usually apparently less

than in ordinary talus slopes, for in falling 2,000 feet or more the bowlders often break and gain unweathered surfaces. But in shape there is a conspicuous difference between subglacial and superglacial fragments. The superglacial material retains its angular form, and is dropped in the terminal moraine without scratches, while the subglacial material is worn and grooved. The result is that those parts of the moraine which are composed of superglacial débris resemble talus, and can be distinguished from it only by their topography.

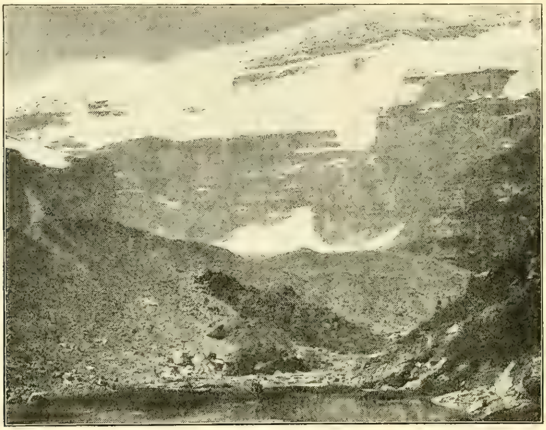

FIG. 7.—Cliff glacier of Mount Victoria, and the side of the Victoria glacier.

The glaciers described above represent the type in this region. Several other glaciers of the same type were seen by the writer, but only one of them lay west of the continental divide. This one is at the head of Lake Oesa.

The steep front characteristic of these glaciers is a feature that has hitherto been recorded only in the case of high-latitude glaciers. Steep fronts are characteristic of both cliff and valley glaciers in the Canadian Rockies, and are due to different causes in the two cases. In the cliff glaciers the steep front of the ends comes from the periodic breaking off of the front of the glacier, the broken end falling over a cliff and leaving a vertical ice face on the glacier (Fig. 7). It occasionally happens that the slopes of mountains on which cliff glaciers rest are bounded by cliffs on several sides. In such cases the cliff glaciers

may acquire steep sides as well as steep ends by this breaking off process. When the rock sides are higher than the floor beneath the ice, the sides of the cliff glaciers are buried in snow, and so, either actually or apparently, are not steep.[1] In the valley glaciers the steep end has some other cause which appears to result from a combination of shape and manner of melting.

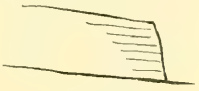

Fig. 8.

These glaciers of the central and eastern Rockies remain approximately constant in thickness, melting on the surface at their upper ends, and beneath the surface at their fronts. The regions of accumulation and of maximum surface melting are similar. Fig. 8 shows diagrammatically the front of one of these glaciers. The upper layers are protected from melting, hence remain intact at the front, while the melting of the lower layers leads to the formation of a cliff and of an angle between surface and front. Glaciers of the ordinary alpine type push forward, at a high gradient, from a region of perpetual snow, melting at the surface and thinning toward their lower ends. Fig. 9 represents the front of one of these glaciers. The end slope may be as steep in the second case as in the first, but there is invariably the difference that among these glaciers there is a gradual curve from surface to end, while among those of the first group there is a sharp angle between a nearly horizontal surface and a nearly vertical front. The slope of the front of the second type of glaciers is determined in part by the gradient of their beds, in part by the rapidity of surface melting at the front. Among glaciers of the first type, slope and surface melting are both at a minimum, and the angle of the front is determined by rate of sub-surface melting.

Fig. 9.

Steep sides as well as steep ends are characteristic of high-latitude

[1] Cliff glaciers were defined by Salisbury in this Journal, 1895, p. 888. The cliff glaciers in Alberta are of a slightly different type from those described from Greenland. They form in essentially the same way, but the ends of the Canadian cliff glaciers usually push over the ends of precipices and break off, leaving several hundred feet of vertical ice which forms an ice-cliff above the rock cliff. Those figured by Salisbury appear to end like steep alpine glaciers. Another point of difference is that these Canadian cliff glaciers lie on the general slope of the mountain and are much broader than they are long, while those in Greenland lie in steep gullies.

glaciers. Among the eastern Canadian glaciers the sides are almost invariably buried either in talus from cliffs or in moraine (Fig. 7). Among the glaciers above described the glacier of the valley of the Ten Peaks, which is advancing laterally, is the only one in which the ice of a side was visible. In this case the side was steep, like the front.

GLACIERS OF INTERMEDIATE CHARACTER

It is impossible to draw a hard and fast distinction between these two types of glaciers, since there are many glaciers, parts of which belong to one type and parts to the other. But in each case it was evident that whenever glacier ice was buried sufficiently to shut out sun and air entirely, surface melting practically ceased.

The Yoho Valley lies on the western side of the continental divide. Though a tributary by name, it furnishes the greater part of the water supply of the Kicking Horse River. The Yoho Valley is a glacial canyon, with rock terraces on its sides. There are six large glaciers on the sides of the Yoho Valley, the water from these glaciers coming over the terraces in falls. One important tributary enters the Yoho from the west. At its junction with the Yoho this tributary forms the Laughing Fall; farther up its course five glaciers lie on its sides.

The glaciers of the Yoho are fed by large snow-fields, for the most part yet unmapped. As a rule, the surfaces of the glaciers are steep, clean, and much crevassed, and their ends have the gradual curve from surface to front illustrated in Fig. 9. The sides of the valley are so steep that the fronts often have a high angle, and ice cascades occasionally occur.

Most of these Yoho Valley glaciers belong to the second type, but three of them combine the characteristics of the two groups. These three lie on the sides and end of Laughing Fall Valley.

One of these glaciers on the north side of Laughing Fall Valley enters its basin over a col between two limestone peaks. Its general direction of flow is eastward over the col; then it cascades over a cliff forming some fine seracs, and turns southward toward the Laughing Fall Valley. The eastern slope of the basin of this glacier, is formed by shale ridge locally called "The Whaleback." The ice, in turning the corner just described, banks itself up against "The Whaleback" and becomes buried in shale. With the shale are mingled rounded limestone fragments from the peaks to the west, the débris being

frozen into the ice and forming a sort of conglomerate. The surface is thickly covered also. The ice thus loaded and protected seems entirely stagnant, neither moving nor melting. The main body of the ice, however, was clean-surfaced. Several recessional moraines showed its retreat.

Similarly a glacier extending northward from Emerald Mountain showed several recessional moraines on its western side, while the eastern portion, which was buried in talus, appeared to be stationary.

At the head of this same Laughing Fall Valley lies a lake, about a mile in length. Its outlet is over rock, its eastern and northern sides are of rock, while its western side is formed by a débris-laden glacier. Besides the ice is a brook, the lower course of which is arched over by snow. The snow patch ends in the lake, and portions of it break off and float away like small icebergs. The glacier appears to be advanced as far as it ever was. There is no moraine in front of it, and no débris could be seen in the water of the lake. Since the water of the lake is remarkably clear, any débris that had been dropped in it could have been distinguished.

The débris of this glacier is apparently derived directly from the mountain behind it, without the assistance of cliff glaciers. This point, in which these three Yoho glaciers are alike, is an important difference between them and the glaciers of the first group. Although resulting in a preservation of the ice in both cases, it is in the Yoho an exceptional and unusual occurrence, while among the glaciers first described the débris covering comes as a necessary part of their mode of origin.

The Lake Louise sheet of the Canadian Survey map, though accurate near the railroad, is in the Yoho Valley entirely a work of imagination. The lake at the head of Laughing Valley, and five large glaciers are omitted entirely, while the position of mountains and slopes of valleys are inaccurate. The sketch map (Fig. 2) accompanying this paper is adapted from this sheet.

GLACIERS OF THE SECOND GROUP

Glaciers of the Yoho Valley.—At the head of Yoho Valley is the Wapta glacier (Fig. 10). This glacier is fed by a great and yet unmapped snow-field. The glacier itself is broad and short. Its

slope is steep; its surface clean and much crevassed; its front, though steep, does not exhibit a cliff.

No records are available as to its rate of motion, but a rapid retreat is evident. Drift material, free of vegetation, is to be found for about three-quarters of a mile from the ice and extending 300 feet up the sides of the valley. The ice descends to a level of 5,000 feet (aneroid).

FIG. 10.—Wapta glacier.

Fed by the same snow-field is another glacier which descends the valley above Twin Falls. This valley is flat and open, the glacier having less slope than the Wapta, and for some reason which is not evident the ice-front does not descend below 5,700 feet. A recent rapid retreat is evident, but the exact amount could not be determined, since fresh landslides have brought down much material which has been mingled with the drift, while both drift and talus are being worked over by the glacial stream.

The Illecillewaet glacier.—Probably the most famous and most often visited glacier in British North America is the Illecillewaet, or

Great Glacier, of the Selkirks (Fig. 11). At a distance of only two miles from the railroad, the glacier is easily reached by a good trail.

It is fed by a snow-field which forms a plateau at a level of about 7,000 feet. From this névé the glacier descends in a great ice cascade to a level of 4,750 feet. Its surface is perfectly clean and much

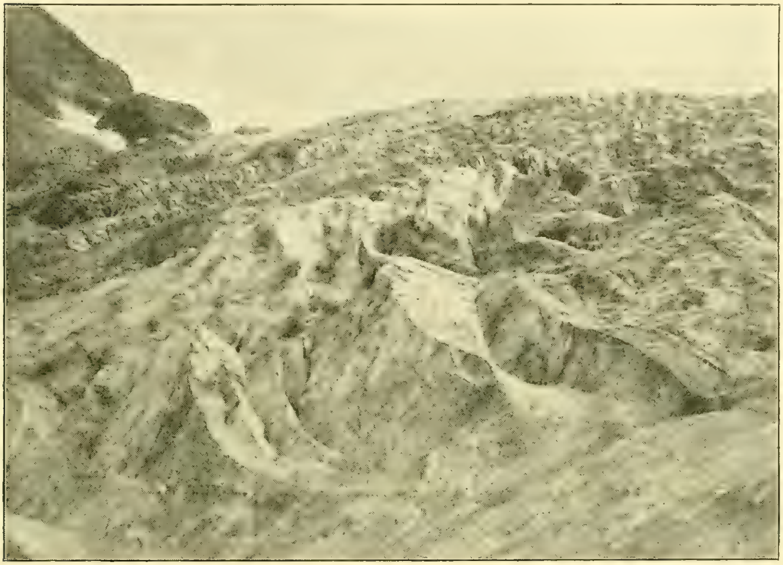

FIG. 11.—Illecillewaet glacier.

broken, seracs and crevasses being abundant. Its front is very little steeper than the average slope of the glacier.

In 1888 Dr. Green found that in twelve days the center of the ice moved 20 feet; the side, 7 feet.[1] Since 1887 Messrs. George and William S. Vaux have made a special study of this glacier. The general average of their observations shows a motion of from 6 to 2 inches daily in different parts of the ice. The great difference between these figures and Dr. Green's may be due to some change in conditions, or to the observations having been taken on different parts of the ice. At all events, Dr. Green's figures seem too high

[1] *Among the Selkirk Glaciers* (Macmillan, 1890).

for the present motion. Since the beginning of the observations of Messrs. Vaux the end of the glacier has been receding rapidly. A general average of their observations gives an annual recession of about 60 feet.

The Illecillewaet névé is some 10 square miles in extent. It lies in a depression between several high peaks, and feeds four large glaciers. A second of these is the Asulkan. During the year 1899–1900 Mr. Vaux reports that this glacier receded 24 feet, but at present it seems to be advancing. When I visited it this summer, the end had pushed forward up and over an old moraine.

The Asulkan and Illecillewaet glaciers are roughly parallel, both moving north. From the same névé comes the Geikie glacier, moving southwest, and the Deville glacier, moving east. There are several lesser, unnamed glaciers at intermediate points. All present the same general characteristics of high gradient, clean surface, and rapid retreat.

CONDITIONS AFFECTING MOTION

Without entering into the causes of glacier motion, it is safe to say that the conditions favoring rapid movement are steepness of slope, great precipitation of snow, little load, and high temperature.

Slope.—The slope is greater in glaciers of the second type than in those of the first type. The Victoria, Ten Peaks, and Consolation Valley glaciers on the east side are almost flat. They appear to lie in valleys of slight declivity, and the continual melting at their upper ends keeps the ice of nearly uniform thickness. But glaciers of the second group have, as a rule, great slopes. The Illecillewaet rises over 2,000 feet to its névé, in a distance of about two and one-half miles. The Wapta is almost as steep, rising about 1,200 feet. The Asulkan has a varied course, having two falls separated by a flatter area, but its general slope is steep. This steepness of slope is due partly to steep declivity of the valley floors, partly to great thickness of the ice in the region of accumulation, with thinning from melting in the region of dissipation. Both from steeper slope of the valley and from greater pressure of a thicker mass of ice above the glaciers of the second type have the advantage.

Snowfall.—Records are kept at the Glacier House with more or

less regularity. The station is nearly 3,000 feet lower than the Illecillewaet névé. The amount of precipitation received by the glacier is therefore probably greater than that of the valley. An average of seven years' observations gives an annual snowfall of 36 feet and 5 inches.

No records are kept in the immediate vicinity of the Rocky Mountain glaciers. Records here would be of less significance, for precipitation is exceedingly local in character. Moreover, owing to the occasional occurrence of Chinook winds, there is far greater evaporation than in the Selkirks. It is safe to say that here, as elsewhere in the Rockies, there is far less precipitation than among the mountains to the west, and that there is more evaporation.

The prevailing winds coming from the west and from the sea, the moisture is first precipitated on the westernmost mountains. As they progress eastward, the prevailing winds have less moisture. Having less moisture, the daily range in temperature becomes greater, and the difference in temperature and in precipitation between valley and mountain slopes, greater. In the Bow Valley, near the glaciers of the first group, the maximum depth of snow in winter is said to be 2 or 3 feet; on the slopes near the glaciers of the same region, 10 or 15 feet. The depth of snow on the ground in the Selkirks, near the Glacier House, is 20 feet or more.

Load carried.—It has been shown by I. C. Russell,[1] and also by Messrs. Chamberlin and Salisbury,[2] that glaciers heavily loaded with débris move more slowly than those which have no load. This is due in part to the lessening of the viscosity of the ice by the introduction of rigid material, and in part to the formation of débris-charged ice-dams at the ends, which hold back the advancing ice. So far as could be observed, the amount of englacial material is small in both types of Canadian glaciers, and there is probably little difference in viscosity from this cause. But it is common for the glaciers of the first type to end in a mass of ice thickly charged with débris and forming a sort of ice conglomerate. This was the case also with the three débris-charged glaciers of Laughing Fall Valley;

[1] JOURNAL OF GEOLOGY, Vol. III (1895), pp. 823–32.

[2] *Ibid.*, 1894–95.

but only in one instance, the side of the Illecillewaet, was it evident among glaciers of the second type.

Thus all the conditions affecting rate of motion are in favor of the glaciers of the second type. They have greater slope, more snowfall, and less retarding load. According to the very meager statistics, their rate of motion is about five times as rapid as that of the glaciers of the first type.

CONDITIONS AFFECTING WASTE

Since, therefore, the glaciers of the second type are retreating with much greater rapidity than those of the first, more waste must be looked upon as the cause. The factors which affect rate of waste may be summed up under (1) amount of rainfall; (2) daily and annual range of temperature above the freezing-point; (3) altitude of the snow-line; (4) topography; (5) amount of sunlight and of air received by the ice.

Rainfall.—The records at the Glacier House show an annual rainfall of 12.98 inches. This amount is too small to be a large factor in wastage, especially when contrasted with the great snowfall. The only records kept in the Rocky Mountains localities are notes of the number of rainy or showery days. These notes show considerable variation in different years, but afford no data for comparison with the western region.

Range of temperature.—For the past seven years records have been kept at the Glacier House. From the end of October until the beginning of March the maximum temperature is below freezing. In March, April, September, and October the average temperature is near the freezing-point, either above or below. In the summer months it is above, with an absolute maximum of 86°. The daily range is 10 to 20°.

At Banff records are kept in the office of the Rocky Mountains Park of Canada. There is much more variation in temperature here, and the daily range is greater, and sometimes involves a rise above the freezing-point in winter. In midwinter temperatures of +40° are not uncommon. The daily range is from 20 to 40°, and sudden intense cold may be followed by warm Chinook winds.

The two climates are in a general way similar. Winter has

practically the same duration at Banff as at Glacier; the absolute maximum temperature at Banff (July 4, 1903) is recorded as 81.8.° The length of hot and cold seasons is approximately the same, and the range above freezing is practically the same.

Such differences as there are would favor a more rapid waste among the first type of glaciers. Occasionally midwinter temperatures above freezing would favor melting; the warm, dry Chinook winds would favor evaporation. Since, therefore, these glaciers are wasting with less rapidity than those of the second type, there must be some other cause than the temperature of the two regions.

Altitude of the snow-line.—In the Selkirks the snow-line is at an altitude of about 7,000 feet. From this level the glaciers descend with a fall of from 1,000 to 2,500 feet.

In the Rockies the snow-line is higher. It is variable, but is in general at an altitude of about 8,500 feet. The débris-covered glaciers end at a level of about 6,000 feet.

Topography.—The general effect of the occupation of a valley by a glacier is to round its outline, changing a V to a U in cross-section. The extent to which this can take place depends (1) upon the structure and character of the rock, and (2) upon the erosive capability of the glacier. The schists and quartzites of the Selkirks are readily rounded, and broad open U's produced in a relatively early stage of erosion. The result is the production of wide areas in which the accumulation of snow is possible. These gentle-sloped depressions aid the great precipitation and low snow-line in the production of the great névé regions.

The Rockies, in the region of the first type of glaciers, are composed for the most part of hard unmetamorphosed limestone, with vertical cleavage. Its tendency is, on weathering, to produce cliffs. The resulting valleys are steep-sided canyons even after their occupation by ice. Any widening out that takes place is below the snow-line, and impossible for névé formation. The small size and sluggish character of the glaciers may be effective of the same result.

The only points of lodgment for snow and ice are in cracks in the faces of cliffs, and here are found the only névés of the region, as feeders of the cliff glaciers. Thus precipitation, altitude of the snow-line, and topography combine to form great névés in the one

region; to prevent this formation, in the other. The result of this method of formation is that the valley glaciers on the east are entirely in the region of melting, and that the new snow supply they receive has no connection with their own forward movement.[1] It might therefore be expected that their rate of melting would be greater than that of the glaciers with great névé regions as reservoirs of accumulation. That this is not the case seems to be due entirely to the remaining factor of waste.

Amount of sunlight and of air received by the ice.—There are two causes which combine to shade the eastern glaciers: (1) shading by the steep cliffs, and (2) covering by débris. The shading by cliffs seems sufficient to determine the general position of the ice in its valley. This position of equilibrium once determined, the débris covering becomes the determining factor. That it is so is shown by the melting of the inter-débris areas, and its effectiveness is due to protection from both melting and evaporation.

GENERAL CONCLUSIONS

The type of glacier here described under the first group is not a common one, and probably exists only in regions of sharp relief and moderate precipitation. Less relief would afford opportunity for snow-fields to accumulate; greater snowfall would fill the valley, connecting the valley glacier with the cliff glaciers above, and so keeping the débris subglacial throughout. Either cause would produce a glacier of the second group—the ordinary type. Among glaciers of this ordinary type the concentration of débris on the surface at the lower end is a part of the process of retrogression, representing a stage of decadence.[2] The ice, if thus protected, is nearly stagnant, and the thickness at the lower end is relatively less than that of a vigorous glacier. This is clearly not the case with the glaciers of the first group; the ice is in motion, its slow movement coming from slight slope and slight pressure; the débris is superglacial; the thickness at the lower end is considerable, and the front

[1] Except in form these glaciers might properly be classed with Piedmont glaciers, which they strikingly resemble. See Russell, "Malaspina Glacier," *Journal of Geology*, Vol. I.

[2] I. C. Russell, *American Geologist*, Vol. IX (1892), pp. 322–36.

is in some cases advancing. These facts show the glaciers to be vigorous and not in the last stages of decline.

The great changes in glaciers come as a response to climatic changes. Slight climatic oscillations take place in periods of about thirty-five years, and now is about the time when a glacial advance is expected. But the advance of these glaciers cannot be due to any such climatic change. Since the winds are deprived of their moisture by the mountains to the west, it is the western glaciers which should first respond to any such change. With the exception of the Asulkan the western glaciers mentioned are all rapidly retreating.

It would thus appear that the débris covering, and that alone, is responsible for the advance, and indeed for the continued existence, of the glaciers of the eastern Rockies.

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Reviews.

A Treatise on Metamorphism. By Charles Richard Van Hise. (Monograph XLVII, U. S. Geological Survey.) Washington, D. C. Pp. 1,286; 13 plates. $1.50.

This treatise is an attempt to reduce the phenomena of metamorphism to order under the principles of physics and chemistry, or, more simply, under the laws of energy. Metamorphism is broadly defined to include all alterations of all rocks by all processes. The metamorphism of the sedimentary rocks was the first subject studied by the author, and metamorphism has been a chief line of investigation with him for more than twenty years. Finding that the alteration of rocks was nowhere systematically treated, he took up the task of preparing such a work. It was supposed that this work would occupy two or three years, but, as a matter of fact, it required seven years, and an eighth year has been needed to put the volume through the press.

The book consists of twelve chapters. Chapter 1 discusses the geological principles upon which a classification of metamorphism may be based. From this discussion it is concluded that the only practicable classification of metamorphism is geological. It is found that the alterations of the outer zone of the earth are radically different from those of the deep-seated zone. Moreover, it is shown that the alterations in the upper zone result in the production of simpler compounds from more complex ones, while those in the deep-seated zone result in the production of complex compounds from more simple ones. The upper zone is called that of katamorphism, and the lower zone that of anamorphism.

Chap. 2, upon the forces of metamorphism, discusses chemical energy, gravity, heat, and light. The manner in which each of the classes of energy produces various mechanical and chemical effects upon rocks is set forth.

Chap. 3 treats of the agents of metamorphism. The agents of metamorphism are gaseous solutions, aqueous solutions, and organisms. Under aqueous solutions the chemical and physical principles controlling the action of ground water and the circulation of ground water are fully discussed. This involves a full résumé of the science of physical chemistry, so far as applicable to the alterations of rocks. This résumé is not simply a summary

from textbooks of physical chemistry, but discusses the applications of the principles to the phenomena of metamorphism.

Chap. 4, upon the zones and belts of metamorphism, discusses these zones and belts from the physical-chemical point of view. It is shown that the alterations of the zone of katamorphism occur with liberation of heat and expansion of volume, the chief reactions being oxidation, carbonation, and hydration. The alterations of the zone of anamorphism occur with absorption of heat and diminution of volume, the chief reactions being deoxidation, silication with decarbonation, and dehydration. Thus the alterations in the two oppose each other. The zone of katamorphism is divided into two belts—that above the level of ground water, the belt of weathering, and that below the level of ground water, called the belt of cementation. While the physical-chemical principles of alteration are the same in each of these belts, the geological processes are very different. The belt of weathering is characterized by solution, decrease of volume, and softening, resulting in physical degeneration. The belt of cementation is characterized by deposition, increase of volume, and induration, resulting in physical coherence.

Chap. 5 treats of minerals. Each of the rock-making minerals is discussed with reference to its occurrence and alterations. The alterations are considered from the physical-chemical point of view. An attempt is made to write chemical equations which represent the transformations, and to calculate the volume relations resulting. It is found that a great number of rock-making minerals undergo two classes of changes, one of which is characteristic of the zone of katamorphism, and the other of which is characteristic of the zone of anamorphism. Perhaps the most important generalization of this chapter is as to the reversibility of reactions in the two opposing zones. This generalization is as follows: The equations which represent the reactions in the zone of katamorphism are reversible in the zone of anamorphism; and, so far as there is expansion of volume and liberation of heat in the upper zone, just so far is there condensation of volume and absorption of heat in the lower zone.

Chap. 6 considers the belt of weathering. The belt of weathering, being the one which is most readily observed, has been treated by many authors. The chapter in this volume on weathering differs from previous discussions in that the phenomena are not considered mainly from the descriptive point of view, the emphasis being given to the classification of the phenomena and their explanation under physical and chemical principles. Also an important feature of this chapter is the consideration of the phenomena of the belt of weathering in relation to the alterations of the other belts of metamorphism.

Chap. 7 treats of the belt of cementation. This belt is defined as extending from the belt of weathering to the bottom of the zone of fracture. The geological results are found to contrast very markedly with those of the belt of weathering. In the latter belt solution is the rule; openings are enlarged; the rocks degenerate. In the belt of cementation, on the other hand, the processes of metamorphism continuously deposit material, the openings are closed, and thus the rocks are consolidated. Each of the cementing substances is considered, and an explanation is offered as to why cementation rather than solution is a general process in this belt.

Chap. 8 treats of the zone of anamorphism. This is the zone in which rock flow occurs. Full explanations of the meaning of rock flow and of the development of such secondary structures as slatiness, schistosity, and gneissosity are offered. Perhaps the most important generalization is that rock flow is mainly accomplished through continuous solution and deposition, that is, by recrystallization of the rocks through the agency of the contained water. But rock flow is partly accomplished by direct mechanical strains. At the beginning of the process, during the process, and at the end of the process, the rocks, with the exception of an inappreciable amount, are crystallized solids.

Chap. 9 treats of rocks. A classification of the sedimentary rocks is given, their genesis is discussed, and the series of transformations through which each of the rocks passes is traced out, the resultant rocks being indicated. It was not found possible to give a similar treatment for the igneous rocks.

With the ninth chapter the subject of metamorphism proper closes, but the results contained in these nine chapters have an important bearing upon other parts of physical geology. The remaining chapters consider these relations.

Chap. 10 discusses the relations of metamorphism to stratigraphy. It is shown that in consequence of metamorphism great difficulties are introduced in stratigraphical work. The nature of the difficulties and the manner in which they may be overcome are fully considered.

Chap. 11 treats of the relations of metamorphism to the distribution of the chemical elements. This is perhaps the most daring of the various attempts at generalizing of the treatise. It is shown that as a result of the forces and agents of metamorphism the elements of the original igneous rocks are redistributed, a given element being less abundant in the larger number of sedimentary rocks than in the original rocks, and corresponding with this depletion each of the elements is segregated in one or more formations. An attempt is made to treat the problem of the redistribution of the elements quantitatively. Assumptions are made as to the total mass of the

sediments and of the relative proportions of the more important classes of sediments. Combining these assumptions with the results of chemical analyses, the losses and gains of various formations for each of the important elements of the earth are considered. Many surprising results are reached. For instance, we find the conclusion that to oxidize the ferrous iron of the original rocks to the ferric condition in which most of it occurs in the sedimentary rocks, 35 per cent. of the amount of oxygen in the atmosphere has been required. But still more startling is the conclusion that to oxidize the sulphur and iron of iron sulphides in order to produce the sulphates of the ocean and gypsum deposits, and to transform the iron to the ferric form, required one and one-half times the amount now in the atmosphere.

The final chapter of the book, 12, is upon the relations of metamorphism to ore deposits. It is probable that this chapter will receive more general attention than any other. The material of the other chapters is of a kind which is likely to be of interest to the geologist only, whereas this chapter is of interest to all men concerned in the great mining industry. The chapter on ore deposits occupies 240 pages, and, indeed, might have been named "The Principles of Ore Deposition." From the author's point of view, the majority of ore deposits are produced by metamorphic processes. Having worked out the general principles of metamorphism with reference to rocks, the author found that the application of these principles to ore deposition explained the majority of ore deposits. From his point of view the proper theory of ore deposition consists mainly in bringing the particular phenomena exhibited by ore deposits under the general principles of metamorphism. The chapter contains a new classification of ore deposits, the fundamental divisions of which are the same as those of rocks. Thus ore deposits are divided into three classes—those of sedimentary origin, those of igneous origin, and those of metamorphic origin. Strictly the treatise on metamorphism should, perhaps, have considered only the third class. However, the first and second classes are sufficiently discussed, so that the relations of these ores to those produced by metamorphic processes may be appreciated. The discussion of ore deposits is too elaborate to be summarized in this general statement. But it may be remarked that for the metamorphic ores an attempt is made to trace out the solution, transportation, and precipitation of each of the chief economic metals. Also the alterations and further segregation of metals are fully considered. The conclusion is reached that in many cases an ore deposit does not represent a single segregation, but is the result of repeated segregations by the same general processes which result in the depletion in certain elements of the various rock formations and their segregation elsewhere. In other

words, the principles of the development of ore deposits are the principles of the segregation of those elements which are of importance to man, but which, for the most part, are so rare that they are not included in the discussion in the chapter on the redistribution of chemical elements.

It is not possible in a summary to give any adequate idea of the scope of this treatise on metamorphism. A very broad range of facts, extending far beyond what might at first be regarded as a part of a treatise on metamorphism, is considered from the energy point of view. It is believed that the volume marks a great stride in the reduction of the entire subject of physical geology to order under the principles of physics and chemistry, and points out the way for a treatment of the entire subject from this point of view.

K.

The Stone Reefs of Brazil, Their Geological and Geographical Relations, with a Chapter on the Coral Reefs. By John Caspar Branner. (Bulletin of the Museum of Comparative Zoölogy, Cambridge, Mass., 1904.) Pp. 285, 91 plates.

This contribution stands almost in a class by itself in that it adds a new variety to the recognized type-formations. While reefs of this class have not been wholly unknown to geologists, they seem to have been regarded rather as individual aberrancies than as expressions of a type dependent on regional conditions and prevalent within the range of those conditions. They have, indeed, been mentioned more or less frequently, but oftenest in such a way as to carry the suggestion that they were coral reefs or some modification of such reefs due to accessions of hardened sand. Their distinctive nature and its peculiarity was recognized by Darwin, Hartt, and a few others, but this comprehensive treatment by Dr. Branner is the first exposition that has brought forth their broader relations and their true significance; indeed, it is the first that has made clear the essential fact that they are not mere aberrant phenomena, due to a fortuitous combination of local conditions, but rather a type of formation, albeit a rare and regional one. While not confined to the coast of Brazil, these sandstone reefs are so limited and peculiar in their distribution, so far as present knowledge goes, as to give special interest to their localization. In the opinion of the author, this regional localization carries genetic significance, and the discussion of this forms a most interesting feature of the book. The peculiarities of these reefs are summarized by the author as follows:

I. They are of sand consolidated to a hard—in places almost quartzitic—sandstone.

II. They stand about flush with the water at high tide, while at low tide they are left exposed like long, low, flat-topped walls, with a width of from five meters to one hundred and fifty meters, and a length of from a few paces to several kilometers.

III. They accompany the shore-line with many and great interruptions from north of Ceará to Port Seguro, a distance of two thousand kilometers.

IV. With unimportant exceptions, the reefs do not occur along the Brazilian coast beyond these limits.

V. They usually stand across the mouths of streams and estuaries, forming perfect natural breakwaters for the small harbors behind them. Sometimes they follow the shore, either on the beach or at a short distance from it.

VI. They are all nearly straight. When crooked, their curves are gentle.

VII. The structure and position of the reefs and the animal remains they contain show that they have been made by the lithification of beach sands in place.

VIII. When stone and coral reefs occur together, the stone reefs are inside or landward of the coral reefs. It is possible, however, that there may be buried coral reefs in some cases to the landward of some of the stone reefs.

IX. The coral reefs are now growing over and upon the stone reefs in some places, while at other places there are stone reefs overlying dead coral reefs.

X. In general appearance, elevation, and position the sandstone reefs bear a striking resemblance to the coral reefs.

The characteristics of these reefs are set forth by careful detailed descriptions, unusually well illustrated by excellent sketches, cross-sections, outline maps, coast charts, and photographic plates (104 figures, 99 plates). The treatment also includes the discussion of several collateral themes, among which are the coast changes, concerning which the following conclusions are drawn:

1. There is no evidence of a perceptible change of level of the coast since the discovery of Brazil.

2. Changes have taken place in the form of the coast-line, and in the adjacent streams, bays, and estuaries in historic times, but they are all accounted for by the ordinary processes now in operation.

3. The stone reefs are not metamorphosed or folded, and they do not rise above tide-level, except in a few instances, where blocks have been tilted by the undermining done by the waves.

4. The coast lakes have been formed by the damming in of estuaries, by the sands blown along the coast, and by the throwing back into the estuaries of detritus cut by waves from adjoining headlands or brought down by streams from the land.

5. The straightness of the coast-line is due to the long period of wearing to which the coast has been subjected, and to the constant on-shore winds and waves along the coast.

6. During the dry season the waves of the sea are able to close the mouths of many of the weaker streams.

7. At such times only the large streams are able to keep their mouths boldly open.

8. Although no changes of level are known to have taken place within the historic period, there are evidences of both elevation and depression of the Brazilian coast in late geologic times.

9. The evidences of depression consist of:

a) The open bays: Rio de Janeiro and Bahia.

b) The partly choked up bays, such as Santos and Victoria.

c) The coast lakes formed by the closing of the mouths of estuaries, such as Lagoâ Manguaba, Lagoâ do Norte, Jiquiá, Sinimbu, etc.

d) Embayments altogether filled up.

e) The islands along the coast are nearly all close in-shore and have the appearance of having been formed by depression of the land.

f) The buried rock channels at Parahyba, now filled with mangrove swamps and mud, show a depression of at least twelve meters since those channels were cut.

g) Wind-bedded sand below tide-level on Fernando de Noronha.

10. The evidences of elevation consist of:

a) Elevated sea beaches, especially well shown about the Bay of Bahia, and along the coast of the state of Bahia.

b) Marine terraces about Ilheos in the state of Bahia. These are about eight meters above tide-level.

c) Horizontal lines of disintegration about one meter above high tide in granites and gneisses at and about Victoria, state of Espirito Santo.

d) Burrows of sea-urchins so far above low tide that sea-urchins cannot now live in them. These are well shown at Pedras Pretas on the coast of Pernambuco.

11. Of the two movements the depression has been much the greater and was the earlier.

12. The great depression probably took place in early Pliocene times (see chapter on Geology, pp. 8–33).

13. Following the Pliocene depression of the coast, the headlands were strongly eroded, the mouths of bays and estuaries were closed, and the coast line was straightened.

14. The standstone reefs of the coast were formed and hardened subsequent to the depression.

15. The coral reefs of the coast have helped build out the shores, and they have likewise protected the land from the destructive action of the waves.

16. The stone reefs have also protected the land, and have helped to prevent the encroachment of the sea.

17. The mangrove swamps have been important agents in building up the newly formed land about estuaries and embayments.

18. The sands of the coast are not of foreign origin, as has been surmised, but are derived from the adjoining headlands, or they have been brought down from the land by streams.

The discussion of the consolidation of the reefs and of the origin of the cementing material is very full and able, assembling and treating critically and judicially a wide range of data and of phenomena, with ample references to the literature of the subject. One of the most interesting points is the relation of the density of the sea-water to the deposition of calcium carbonate, and the genetic connection of the stone reefs with the density of the adjacent oceanic waters and with the surrounding climatic conditions. The conclusions relative to the consolidation of the reefs are as follows:

Stone reefs are formed where there are streams or lakes of fresh water entirely or partially restrained by the beach sands. The new reefs may be formed either in front of the old ones, or in the embayment and estuary behind the older ones. For similar reasons, stone reefs may form behind or landward of the coral reefs. This can only happen, however, in places where marine currents prevent the land-water from interfering with the growth of coral reefs.

The local lithification of the sea beaches is not uncommon, but the most noteworthy instances of lithification on a large scale are those of the northeast coast of Brazil and of the Levant.

The cementing material of the Brazilian stone reefs is chiefly lime carbonate.

The hardening of beach sands may be produced in the following ways:

1. By carbonated rain-water dissolving out the lime carbonate in the upper portions of calcareous sands and depositing it in the lower portions.

2. By the escape of carbon dioxide from the sea-water when the surf breaks upon the beaches.

3. By the escape of carbon dioxide from sea-water where it is warmed by the tropical sun.

4. By the submarine escape of carbon dioxide about volcanic vents.

These processes may have contributed somewhat to the hardening of the Brazilian reefs, but they do not seem competent to account for them altogether. These theories are especially incapable of accounting for the lithification of beaches behind older reefs.

The distribution of the consolidated beaches of northeast Brazil leads to the inference that the consolidation is directly related to the density of the sea-water. The geology and climatic conditions over the adjacent land are, however, important factors in the hardening of the reef sands. It seems probable that the consolidation of the reef sands would not take place if the rainfall were large enough and constant enough to keep the mouths of the streams open and the water of the streams fresh.

In a region of concentrated rainfall and long drouths the river mouths become temporarily closed, and the abundant aquatic and other life in the lagoons thus formed contributes to the organic acid of the waters which, upon penetrating the wall or dam of beach sand, first dissolves the lime, and then redeposits it when it comes in contact with the dense sea-water on the ocean side. In this manner some portions of the beaches have been hardened, while others have remained incoherent.

The density of the ocean water is in all probability considerably greater during the dry than during the rainy season, and this would still further hasten the consolidation of the beaches during dry seasons.

The process of beach-hardening is not a continuous one, but varies with geographic and climatic conditions. New reefs may be formed behind the older ones on the shores of the estuaries and embayments.

The monograph is closed by a chapter on the associated coral reefs.

T. C. C.

The Copper Deposits of the Encampment District of Wyoming. By ARTHUR C. SPENCER. (Professional Paper No. 25, 1904.) Pp. 107; 2 plates and 49 figures.

THE district of which Mr. Spencer treats in this report comprises some 450 square miles in southern Wyoming, so situated that the southern boundary of the area lies close to the Colorado line, while the one hundred and seventh meridian bisects it. The encampment district is crossed diagonally from southeast to northwest by the irregular line of the Continental divide, which is the crest of the Sierra Madre Mountains. The maximum elevation is 11,007 feet (Bridger Peak), and the minimum 6,650 feet.

The structure is essentially a low arch or anticline whose axis is parallel with the mountain crest, that is, east-west. The core of this arch is made up of a mass of hornblende schists and sedimentary rocks, closely folded and overturned to the north, the whole forming a complex east-west synclinorium. These rocks are said to be pre-Cambrian, though the reasons for this conclusion are not given. They were invaded at a later period by basic igneous rocks related to gabbros. The hornblende schists appear everywhere to be the basement upon which the sediments were laid down.

Flanking these pre-Cambrian rocks is a series of Mesozoic and Cenozoic sediments which are now confined to the southwestern part of the area, as a remnant of a great mantle of sediments that formerly covered the whole arch. These formations dip away to the south beneath the surrounding prairie. The oldest of these formations is the "Red Beds" series of the

Trias. Above these lie Jurassic, Cretaceous, some small patches of Tertiary strata, and, on the higher elevations, glacial deposits.

The pre-Cambrian rocks and the intruded gabbro are the most important from the standpoint of the economic geologist, for it is with these that the ore deposits are connected.

As indicated by the title of the paper, copper ores are the chief ores of this district, though some lead and silver, and a trifling amount of gold, in quartz veins, have been found. The copper minerals comprise chalcopyrite, bornite, chalcocite, and covellite, with their usual alteration products. The principal gangue minerals are quartz, calcite, siderite, feldspar, hornblende, epidote, and garnet.

Some of the metallic sulphides crystallized contemporaneously with the silicate minerals of the rocks; others are supposed to be of later origin, and to have been formed by impregnation of the schists by the intrusive norite. A common origin by aqueous deposition is assigned to the remaining ores, and they are found in all channels of easy circulation. Their ultimate source is attributed to the basic igneous rocks of the region, which contain appreciable amounts of copper, and in many cases cobalt and nickel as well.

The most important ores commercially are those (chalcocite) found along the bedding planes and brecciated zones in the pre-Cambrian quartzite. Here secondary enrichment has taken place.

W. D. S.

Recent Seismological Investigations in Japan. By BARON DAIROKU KIKUCHI. Private Publication.

THIS important paper was prepared as an address to be delivered at the Congress of Arts and Science at St. Louis, but, as the author was unexpectedly prevented from attending the Congress, it was printed privately and distributed by him. It is, however, a much more elaborate paper, and much more amply illustrated, than would be inferred from the statement that it is an address. It covers 145 pages, and is accompanied by 54 illustrations relating to earthquake effects, earthquake-proof structures, instruments of observation and their records, geographic distribution, and related subjects. The paper sets forth with much fulness the work of the Earthquake Investigation Committee of Japan in connection with the Seismological Institute of the Tokyo University—work which must be regarded as among the most important now in progress. A chapter is given to the geographical and chronological distribution of earthquakes—

subjects to which the records of this "land of earthquakes" make exceptional contributions. Under the time distribution, the annual, diurnal, lunar, and other periodicities are considered. The most impressive feature of the geographical distribution lies in the fact that the frequency of the Japanese earthquakes increases toward the sea border, especially toward that portion of it which overlooks the great "deeps," and not toward the mountainous axis of the islands.

The instruments used in Japanese investigations are described, illustrated and discussed, as well as the nature of the oscillations which they detect and record..

In the discussion of the velocities of propagation of the seismic vibrations to distant points, preference is given to the view that the paths are essentially parallel to the surface, and not chords, as held by Milne, Knott, Dutton, and others (see previous review). The grounds for this are not made quite clear; at least they are not quite clear to the reviewer. The view involves the supposition that the ratio of elasticity to density in the different horizons near the surface of the earth varies so greatly that, while the main vibrations move at about 3.3 kilometers per second, the advance tremors move at about 14 kilometers per second, or more than four times as rapidly. Professor Nagaoka's investigations of the elastic constants of rocks (see table in Dutton's work, pp. 230, 231) give computed velocities for the fastest or normal wave ranging from 1.19 to 7.05 kilometers per second, the average of sixty-seven determinations made upon various surface rocks being 3.85 kilometers per second. When some little allowance is made for the fractured condition of the crust, this tallies well with the observed superficial rate of propagation, 3.3 kilometers per second. Selecting the Archean and eruptive rocks as being more nearly representative of the material of the sub-crust, eighteen determinations give an average velocity of only 3.75 kilometers per second. The compact Paleozoic rocks prove to be as elastic as the eruptives. The average of the highest eight of the whole list is only 4.95, or a little more than one-third the maximum velocity of the preliminary tremor. If the velocities of these select examples were computed for an unlimited rock medium, instead of a bar, they would average 5.79 kilometers per second, which is still less than half the requisite velocity. As no single rock was found to have much more than half the requisite velocity computed on the assumption that the preliminary tremors went around the spheroid parallel to the surface, and as the speed of the fastest form of wave in an unlimited medium of *steel* under surface pressure is theoretically only about 6.2 kilometers per second, it seems a rather arbitrary assumption that any substratum in the outer part of the earth

would give so high a velocity as 14 kilometers per second. On the supposition that the line of propagation is a chord, a velocity of 9.25 kilometers per second is required, which might more easily be supposed to be supplied by the high pressure of the deep interior, since pressure seems to increase rigidity faster than it does density (Dutton's work, p. 234). The most probable path is a chord-like curve convex toward the center of the earth, so chosen automatically by the wave as to give the most effective combination of shortness of path and superior elasticity, since the latter probably increases toward the center so as more than to overbalance the increased density. So far as giving us light on the physical condition of the interior is concerned, it is of the most vital importance that the correct interpretation of the path pursued by the vibrations be entertained.

The address brings out the gratifying fact that collateral investigations on the associated geological conditions, the earth's magnetism, gravity, underground temperature, and other related subjects, are being made by the Earthquake Investigation Committee. They are also engaged in practical studies for the reduction of the disastrous effects of earthquakes, and structural plans for houses are discussed and illustrated in the paper.

T. C. C.

Earthquakes in the Light of the New Seismology. By Clarence Edward Dutton, Major U. S. A. New York: G. P. Putnam's Sons; London: John Murray, 1904.

This is a very lucid, appreciative, and trustworthy exposition of the recent important advances in seismology, and is in every way a most welcome contribution to the literature of the earth-sciences. Geologists have only partially realized the profound contribution which the new seismology is in process of making to the fundamental concepts of geology. It is perhaps necessary to guard the statement by saying that seismology is in the process of making, rather than has already made, a profound contribution to geologic fundamentals, for the contribution is dependent on the correctness of the belief that seismic vibrations pass *directly through* the body of the earth, as well as around its surface, and that the traversing waves are those that are first recorded by seismographs at distant points on the surface. It cannot as yet be absolutely affirmed that these preliminary vibrations actually traverse the deep interior. This is the interpretation of most of the leading seismologists, and is probably the correct one. Still it must be recognized that this is not yet proved, and that Baron Kikuchi (see preceding review) and others hold the view that these vibrations pass

around the centrosphere in a rather deep portion of the crust rather than directly through the body of the earth. So, too, it is necessary still to speak qualifiedly, for the chief value of the anticipated seismic contribution depends not only on the verity of the passage of the foremost vibrations through the heart of the earth, but also on the transverse character of the second set of these vibrations; for transverse vibrations are functions of solid bodies, but not of liquids, and hence their significance relative to the physical state of the interior. When it shall be shown beyond reasonable doubt that the second set of the transmitted seismic vibrations are transverse, and that they have passed through the center of the earth, it will have been shown with equal conclusiveness that the earth is solid throughout, save for such local spots as vulcanism requires, which would not affect the general power of transmission. Major Dutton brings out the data bearing on this chief point of fundamental interest carefully and conservatively, and makes them readily accessible to the geological inquirer who is not in possession of the special seismological literature. As best interpreted at present, the data seem to indicate not only a thoroughly rigid earth, but one in which there is an increase of elasticity of form toward the center in a ratio at least as high as the increase in density. This last is determined by the speed of wave-transmission, which is made the subject of three chapters.

While these difficult themes of supreme interest to the student of geological fundamentals are given due place in the later chapters of the book, they are not allowed to displace the more superficial and impressive phenomena that have given to earthquakes their universal, if somewhat gruesome, interest. The descriptions of the destructive effects are ample, but always clothed in chaste and sober scientific terms. The illustrations are select, and expressive of definite rather than promiscuous effects.

Much space is given to the instruments used in the more refined observations that characterize the new seismology, and to the methods by which the science is being advanced. The causes of earthquakes occupy a chapter; their distribution and geographic relations occupy two, and the book is closed by a chapter on seaquakes, the distinctness of which from earthquakes is usually overlooked. The treatment, while careful and exact, is not mathematical, except in a few cases where accurate expression would otherwise be impossible. The literary elegance which graces all of Major Dutton's writing finds as large an expression here as the nature of the subject permits.

T. C. C.

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